US007945064B2

(12) **United States Patent**
O'Brien, Jr. et al.

(10) **Patent No.: US 7,945,064 B2**
(45) **Date of Patent: May 17, 2011**

(54) **INTRABODY COMMUNICATION WITH ULTRASOUND**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 2049 days.

(21) Appl. No.: **10/409,970**

(22) Filed: **Apr. 9, 2003**

(65) **Prior Publication Data**

US 2004/0202339 A1 Oct. 14, 2004

(51) **Int. Cl.**
H04R 25/00 (2006.01)

(52) **U.S. Cl.** **381/312**; 381/315; 455/100

(58) **Field of Classification Search** 381/312, 381/314–318, 320–323; 455/93, 100, 556.1
See application file for complete search history.

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Primary Examiner — Suhan Ni

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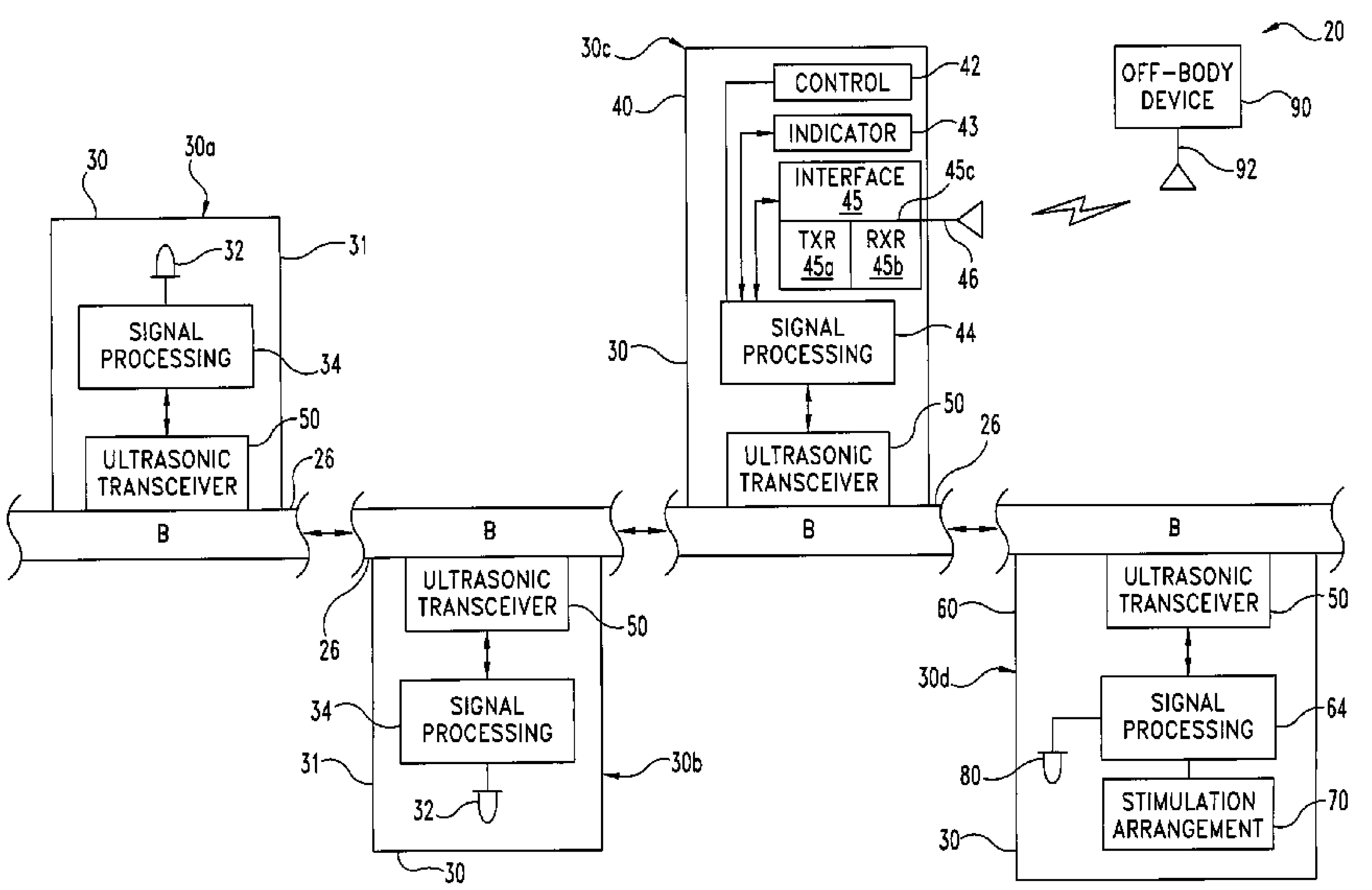
(57) **ABSTRACT**

A hearing system has a first device and a second device. The first device acoustically couples to skin of a user of the hearing system and includes a sensor to detect acoustic signals. The second device includes a hearing stimulator arrangement to stimulate hearing of the user in response to the acoustic signals detected with the first device. The first device and second device are each operable to bidirectionally communicate through an ultrasonic communication link comprising at least a portion of the body of the user.

8 Claims, 12 Drawing Sheets



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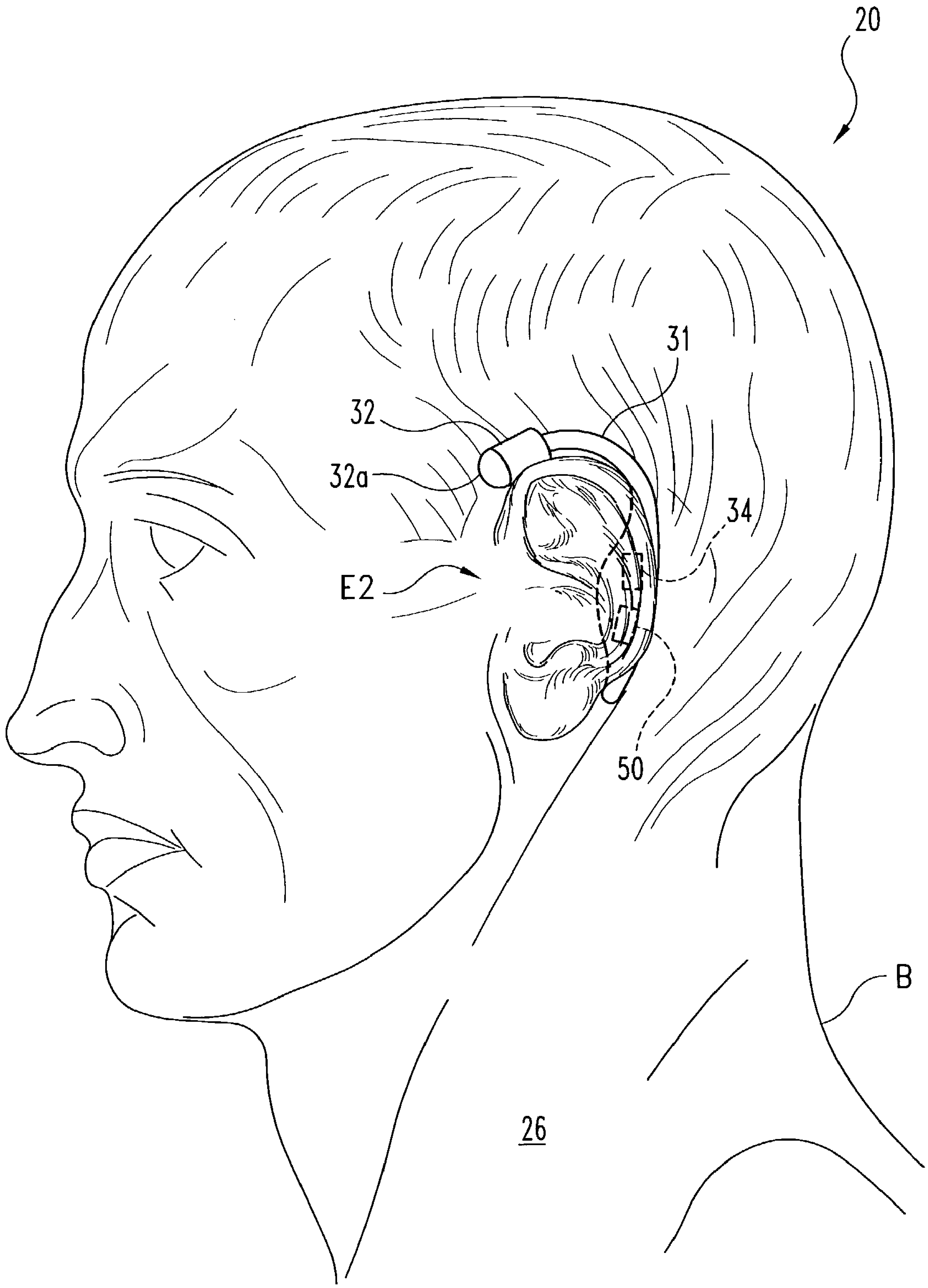
32
32
31
30d
32a
31
20
30
30a
30b
E2
E1
21
26
B
26
50
42
30c
41
43
30
40

Fig. 1



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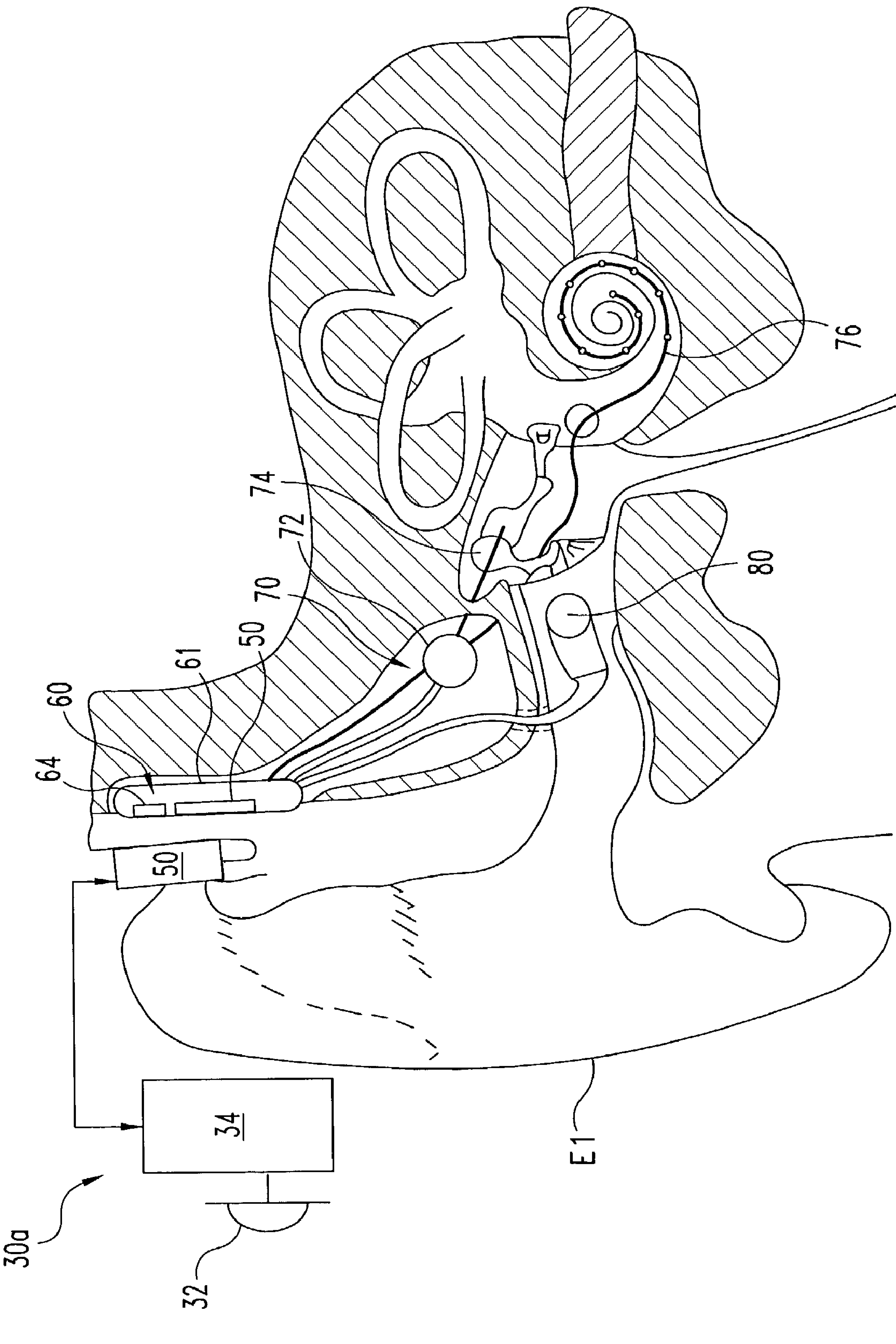

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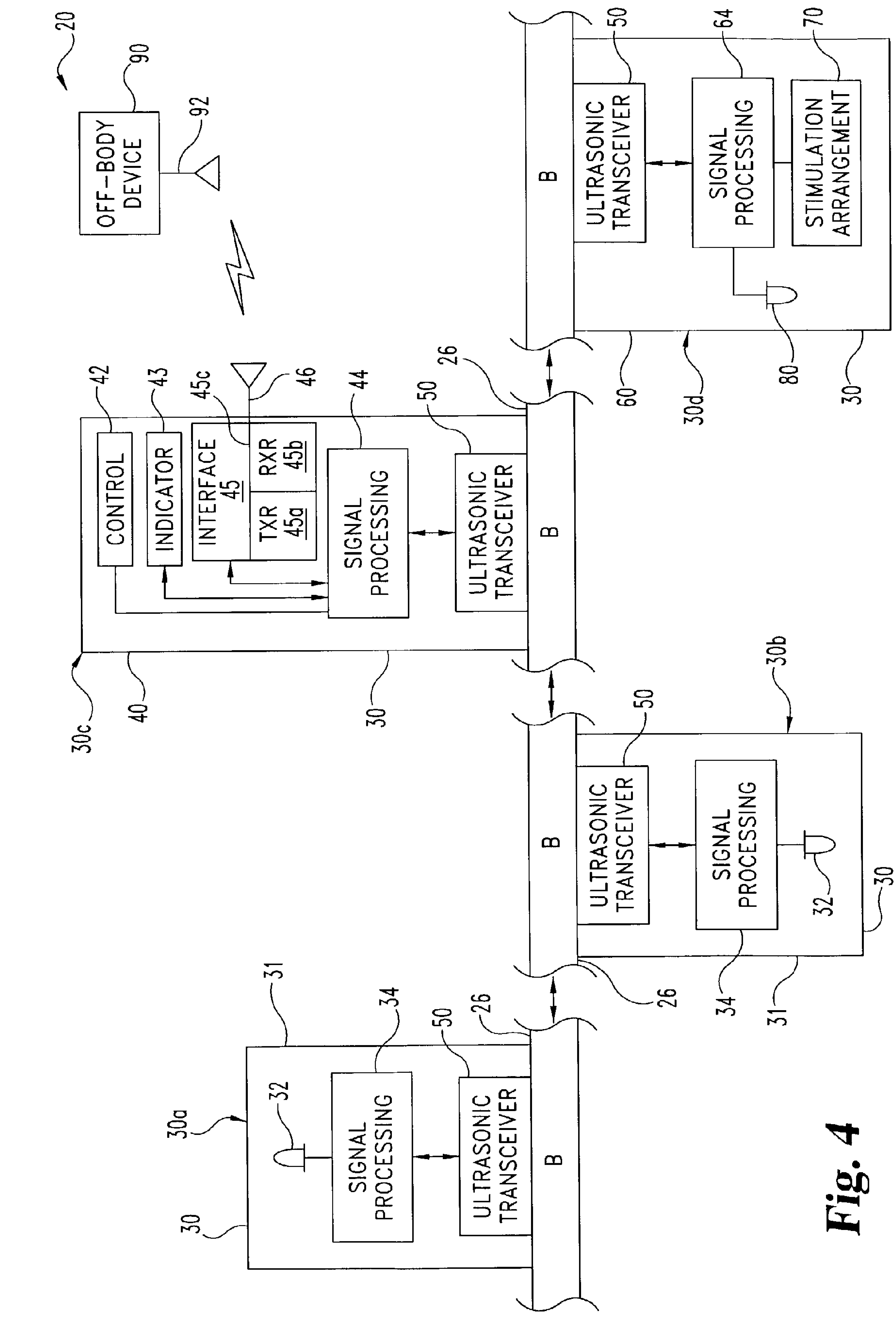
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INDICATOR
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INTERFACE 45
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RXR 45b
45c
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SIGNAL PROCESSING
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ULTRASONIC TRANSCEIVER
50
26
B
30c
40
30
ULTRASONIC TRANSCEIVER
SIGNAL PROCESSING
STIMULATION ARRANGEMENT
64
70
60
30d
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SIGNAL PROCESSING

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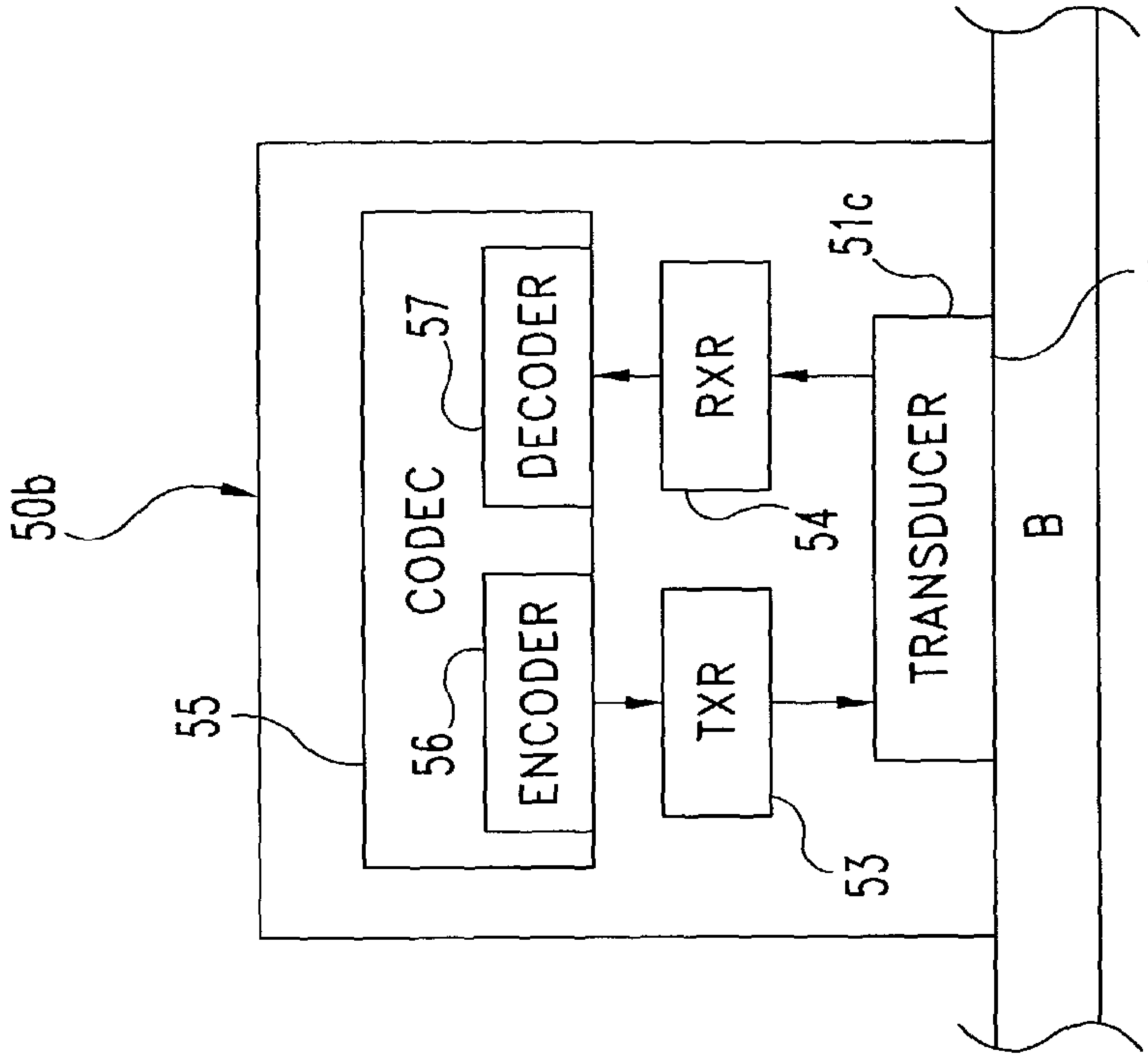
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ENCODER
57
DECODER
TXR
RXR
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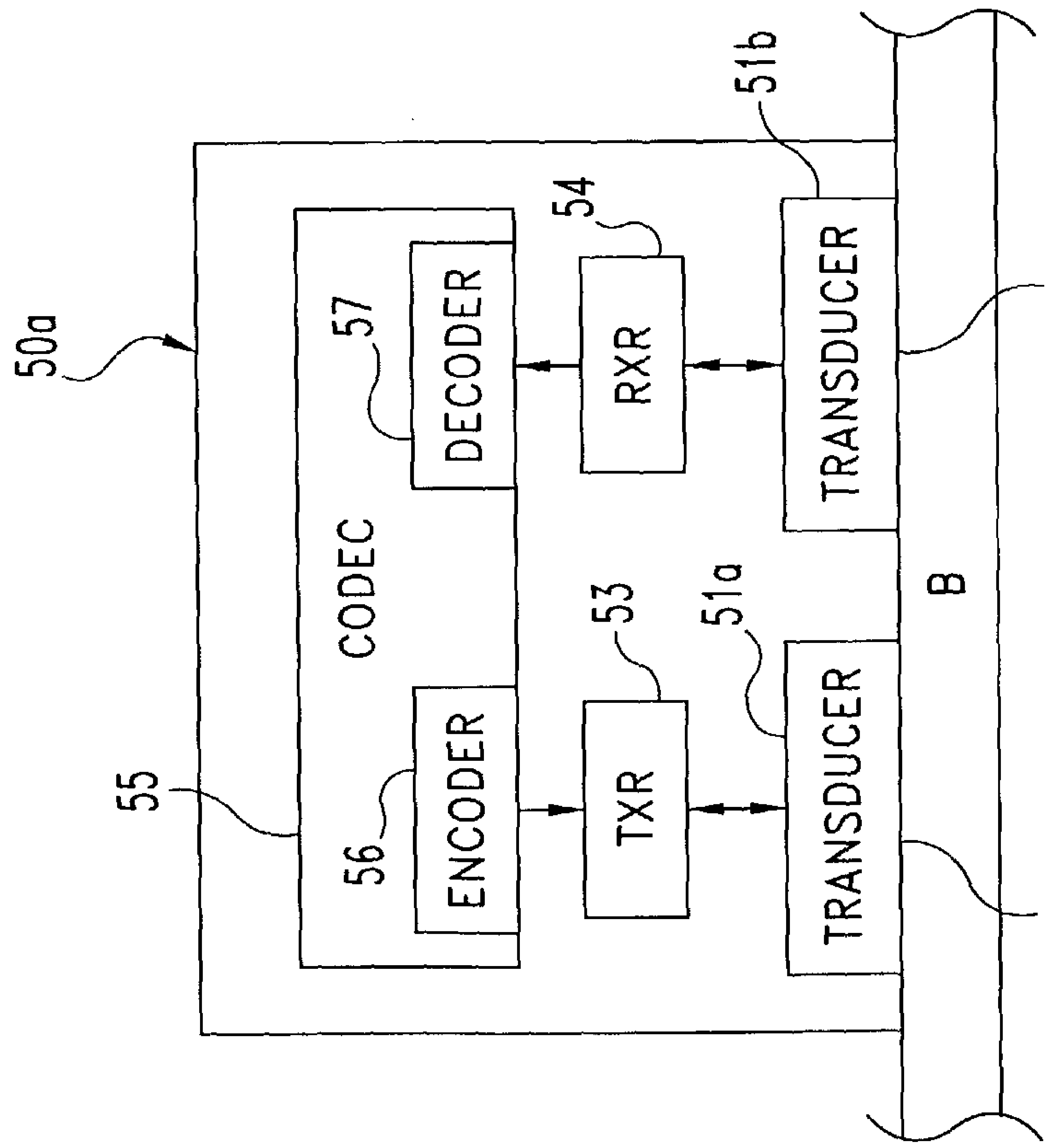
51c
TRANSDUCER
52c
B

Fig. 6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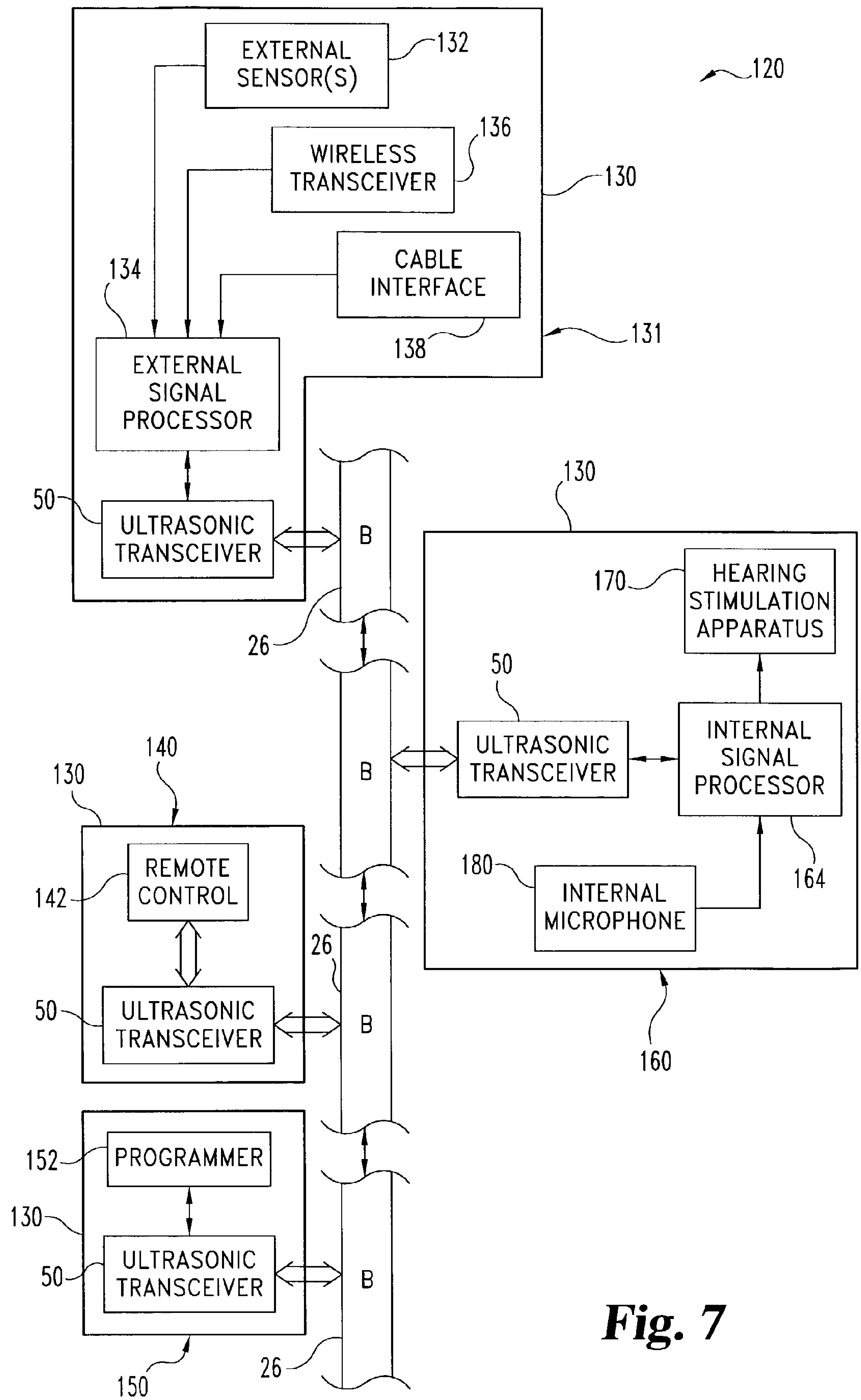
52a
52b
B

Fig. 5



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WIRELESS TRANSCEIVER
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CABLE INTERFACE
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EXTERNAL SIGNAL PROCESSOR
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130
HEARING STIMULATION APPARATUS
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26
50
ULTRASONIC TRANSCEIVER
INTERNAL SIGNAL PROCESSOR
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130
B
REMOTE CONTROL
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INTERNAL MICROPHONE
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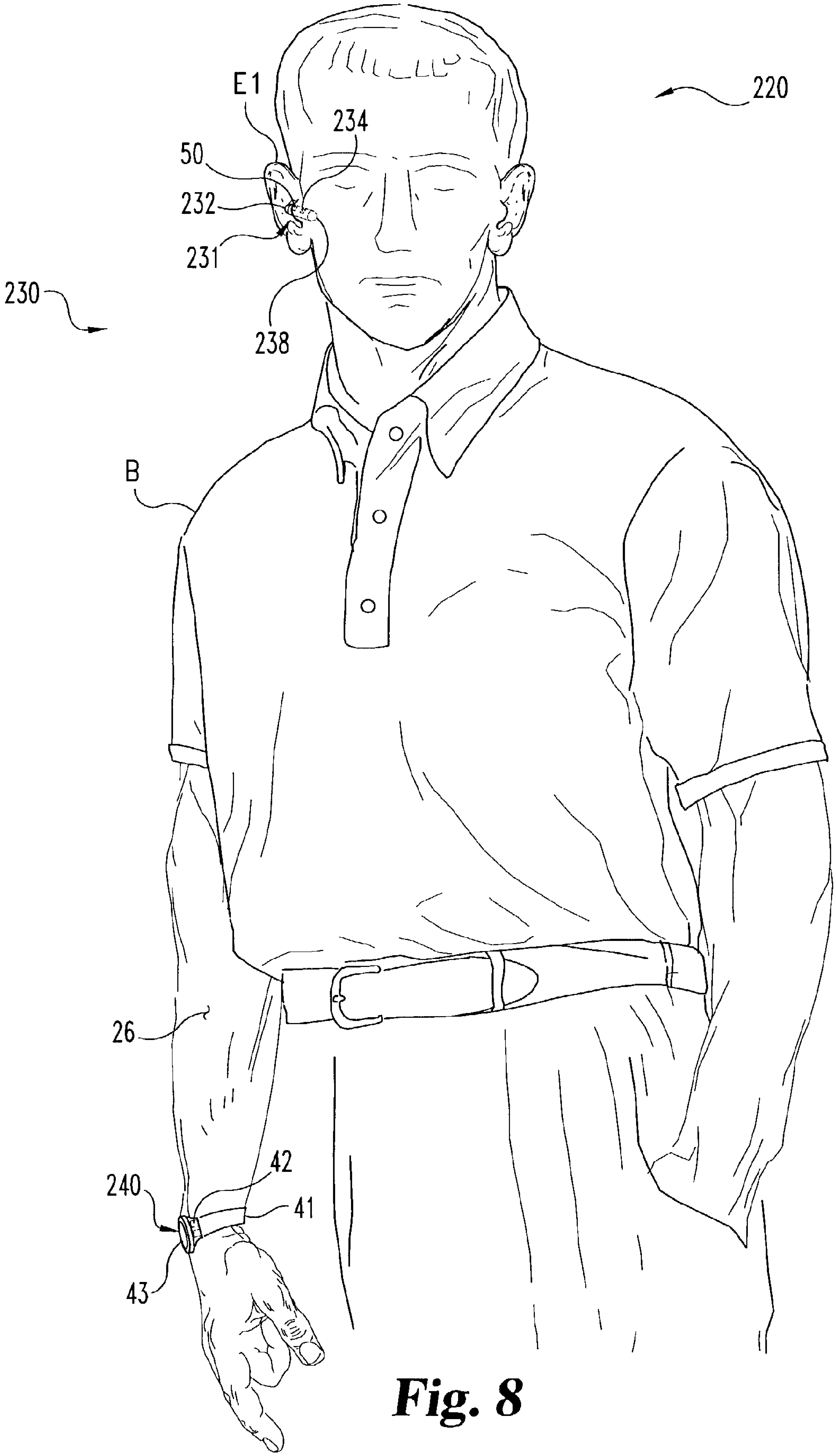
Fig. 7



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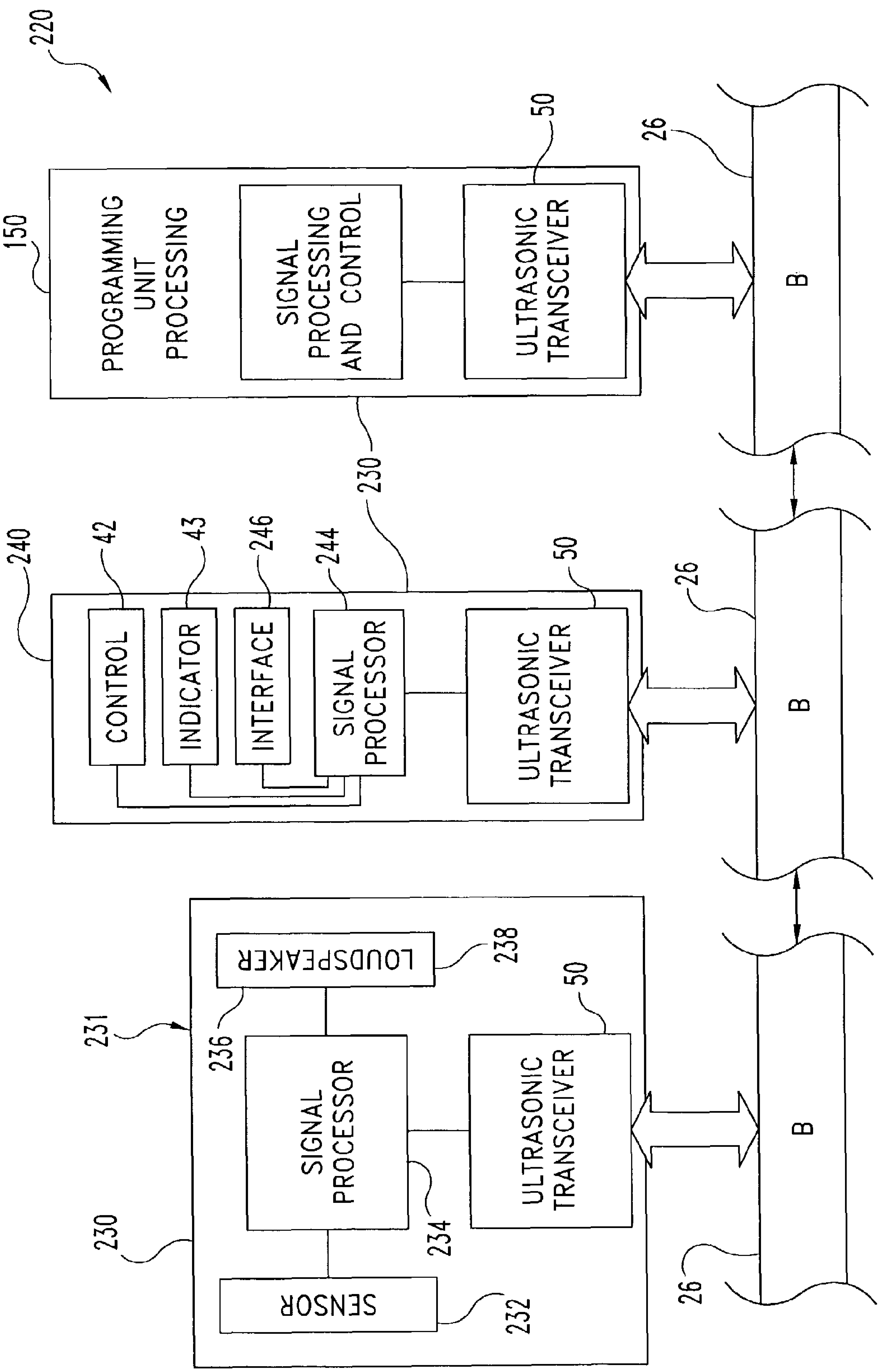
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CONTROL
INDICATOR
INTERFACE
SIGNAL PROCESSOR
ULTRASONIC TRANSCEIVER
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26
B
231
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LOUDSPEAKER
SIGNAL PROCESSOR
ULTRASONIC TRANSCEIVER
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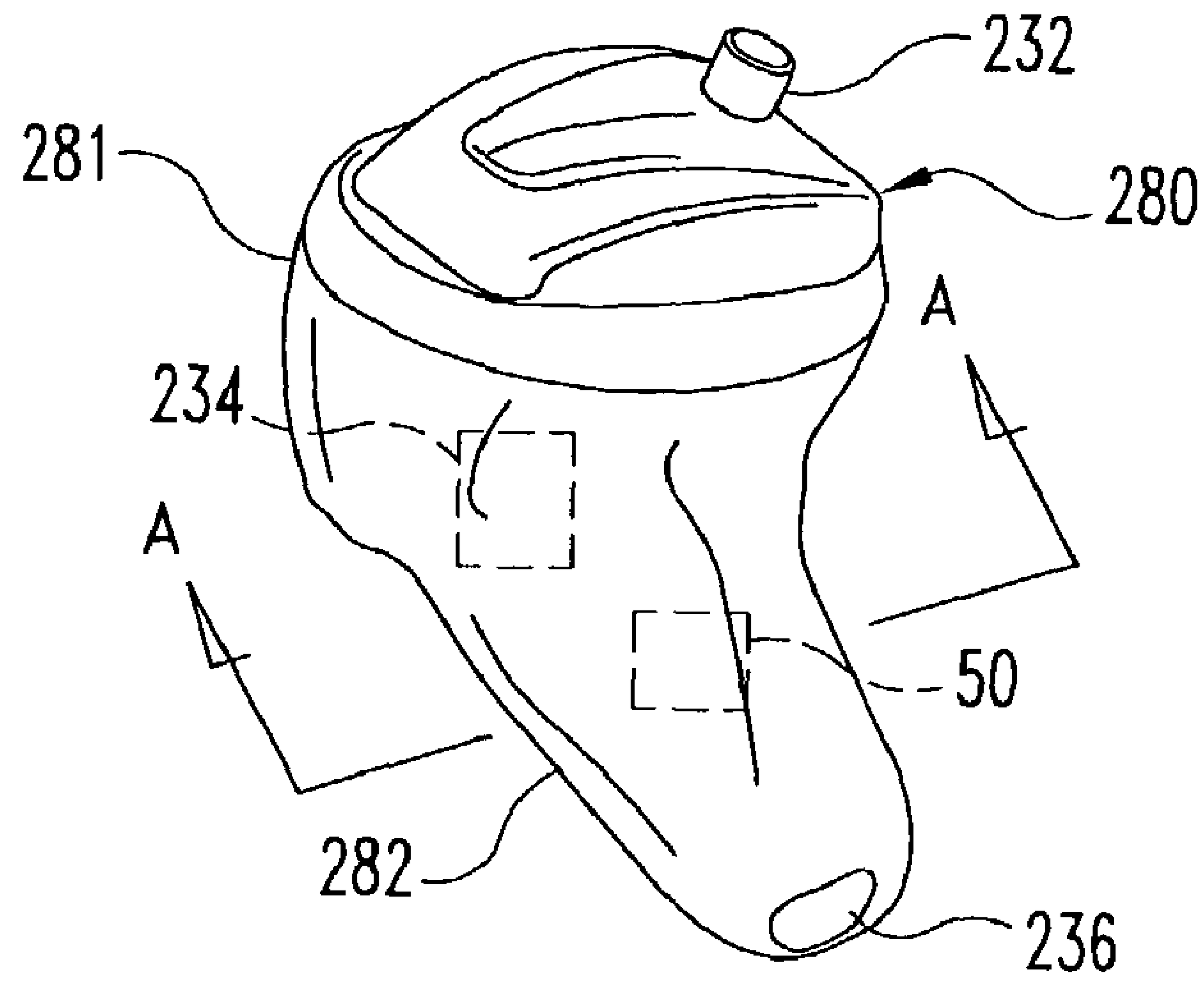
SENSOR
232
26
B

Fig. 9



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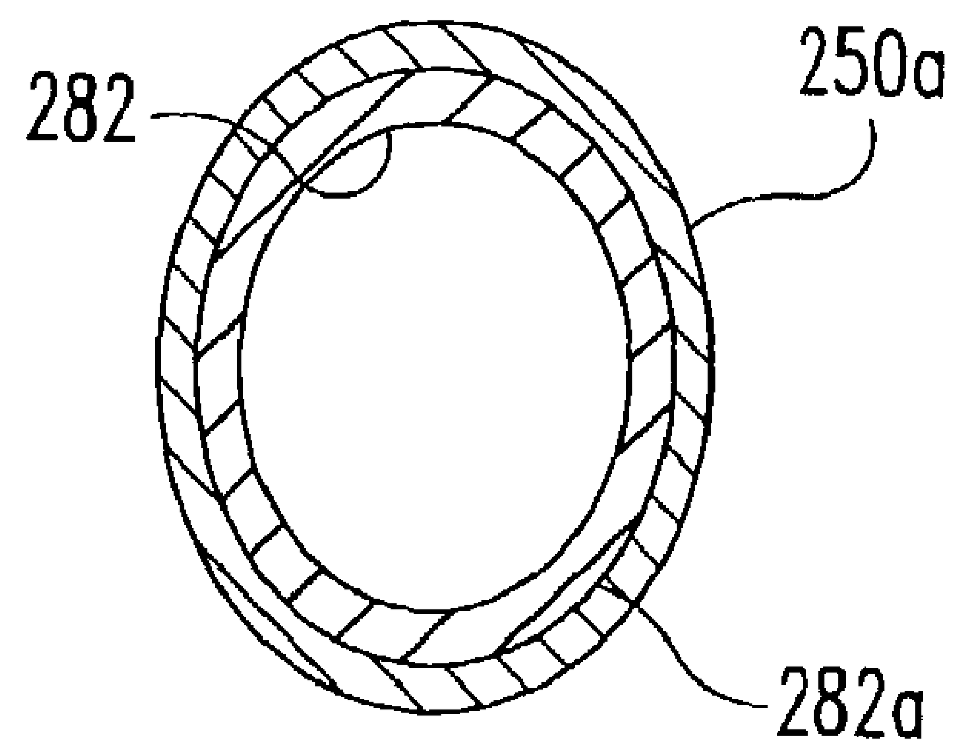

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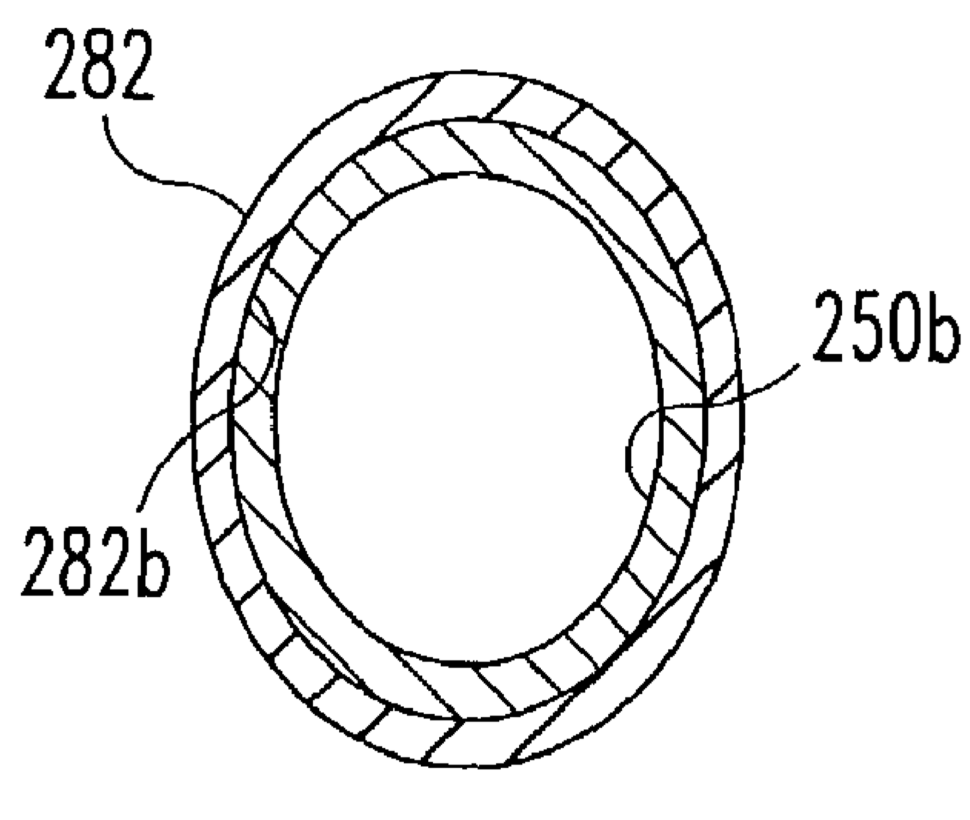

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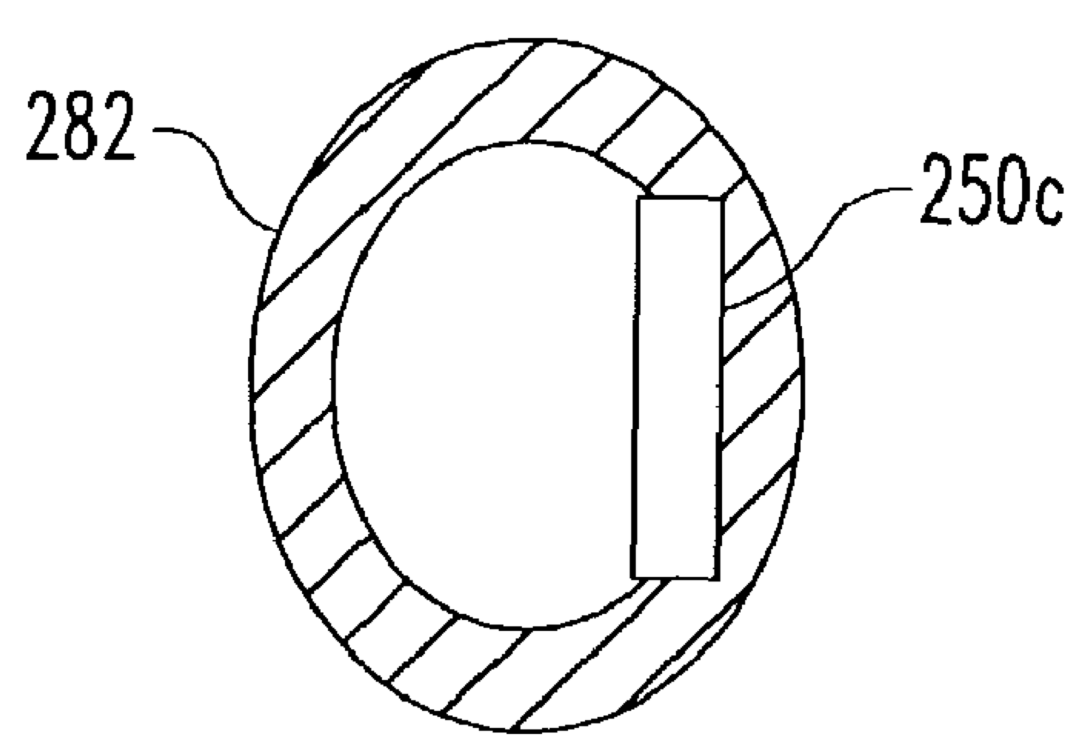

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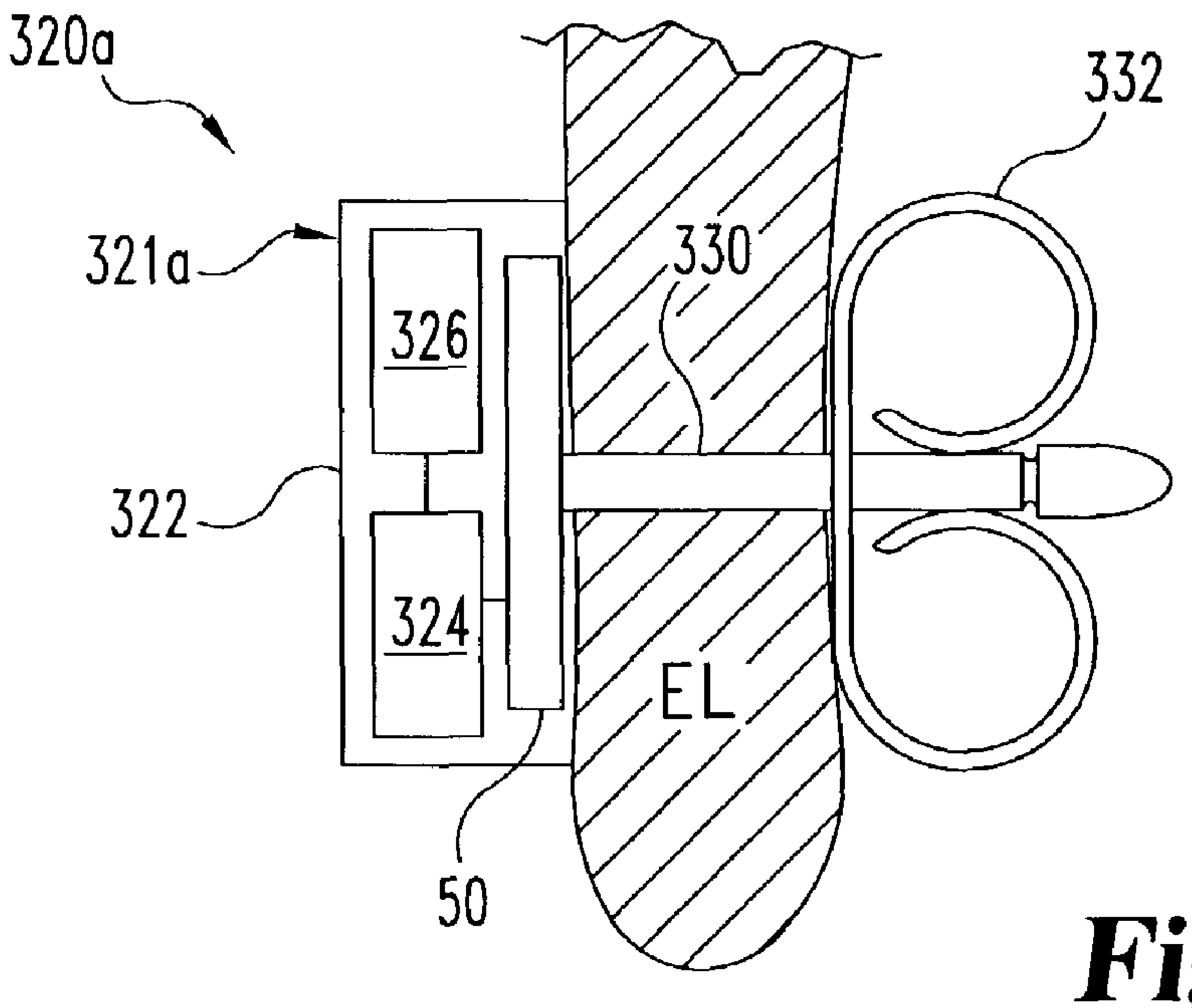
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Fig. 14

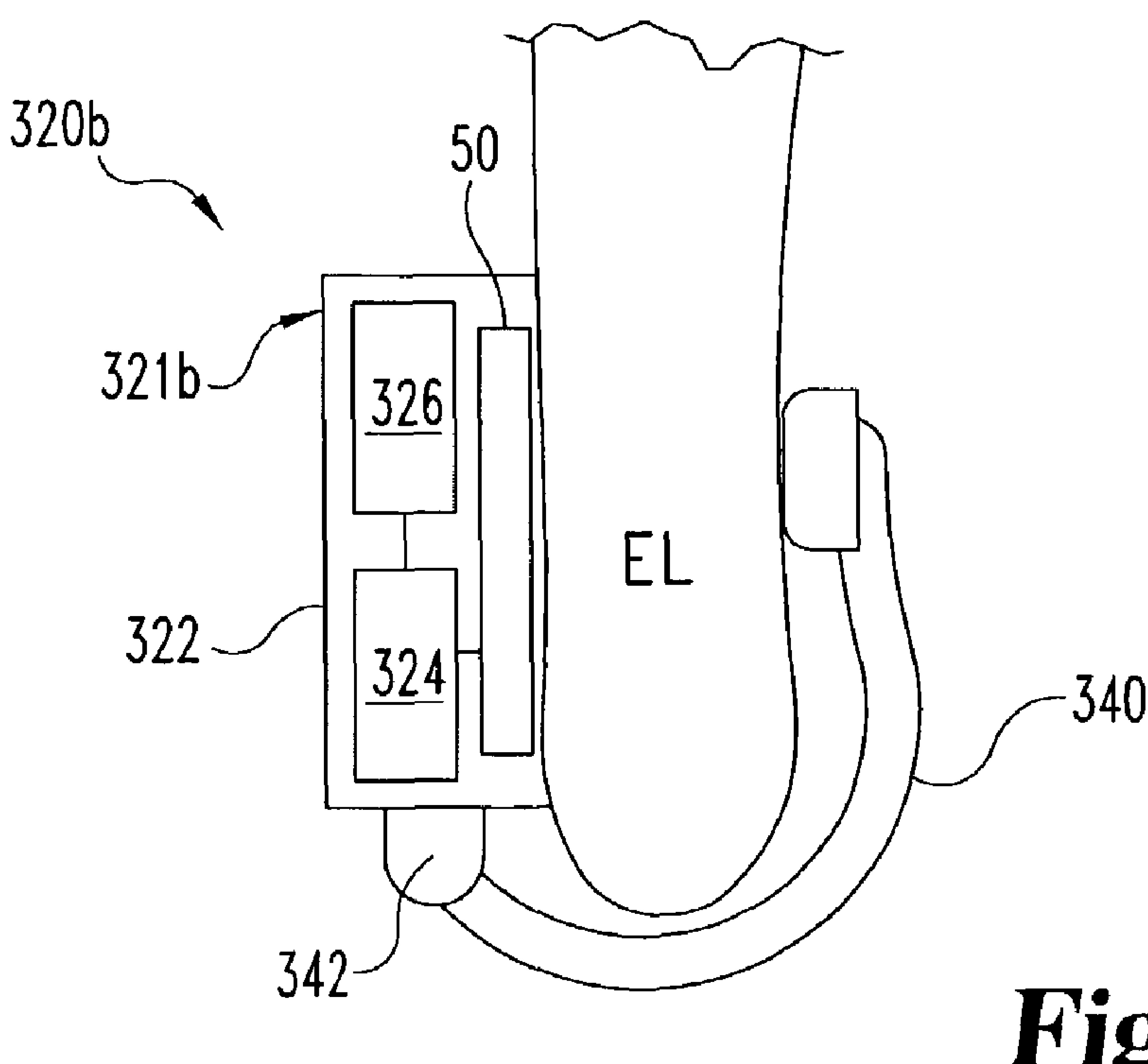
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Fig. 15

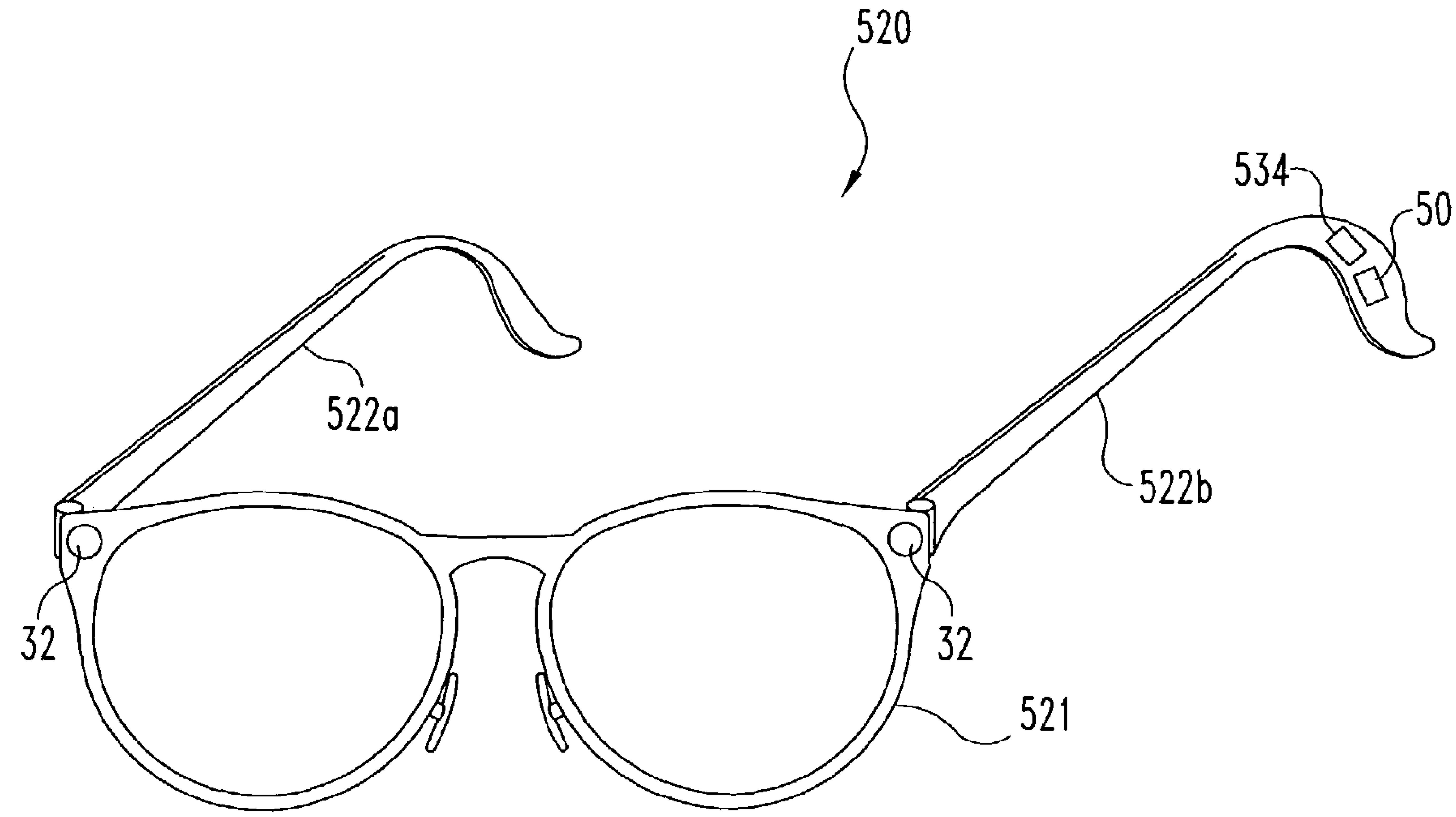
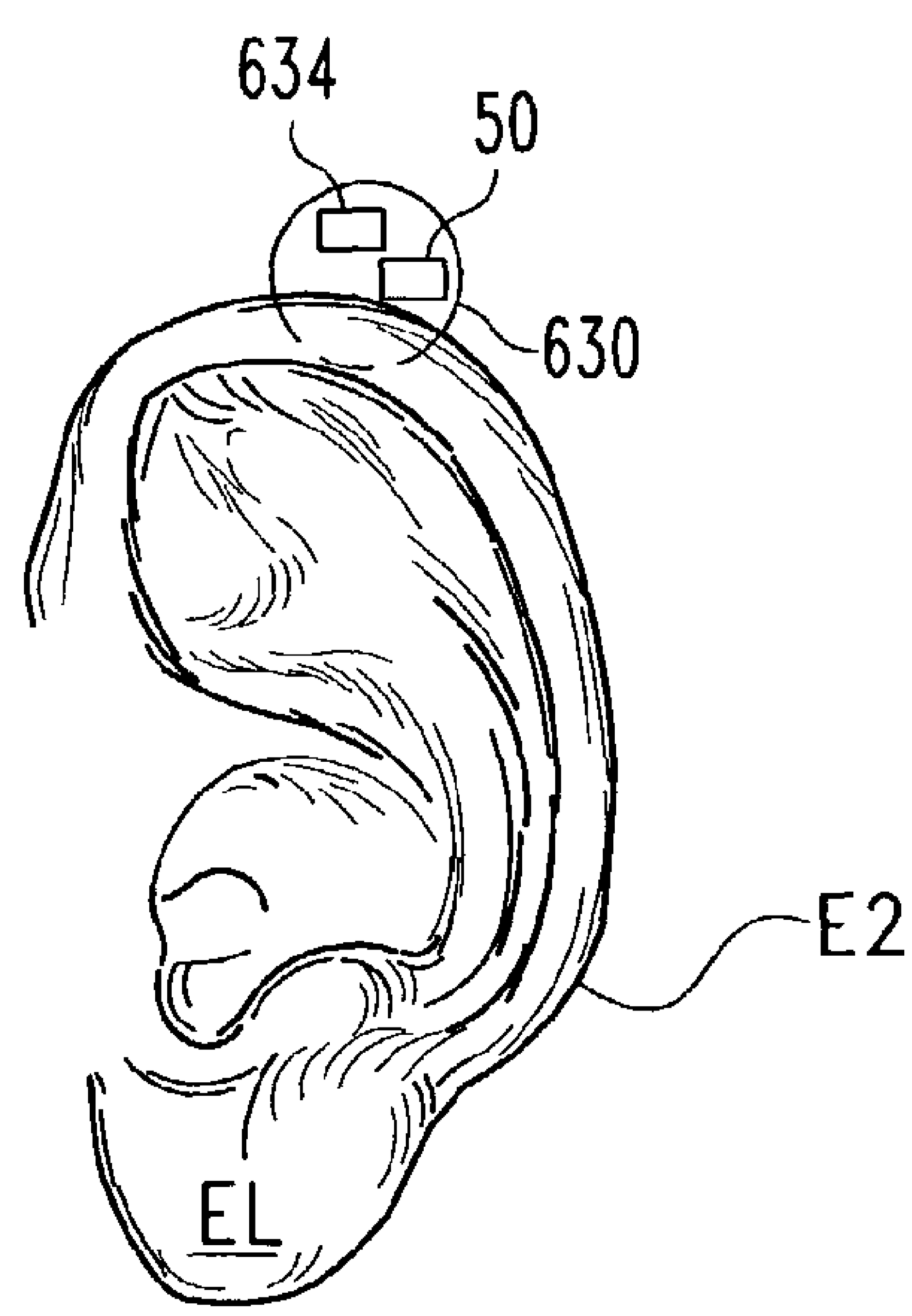


Fig. 16



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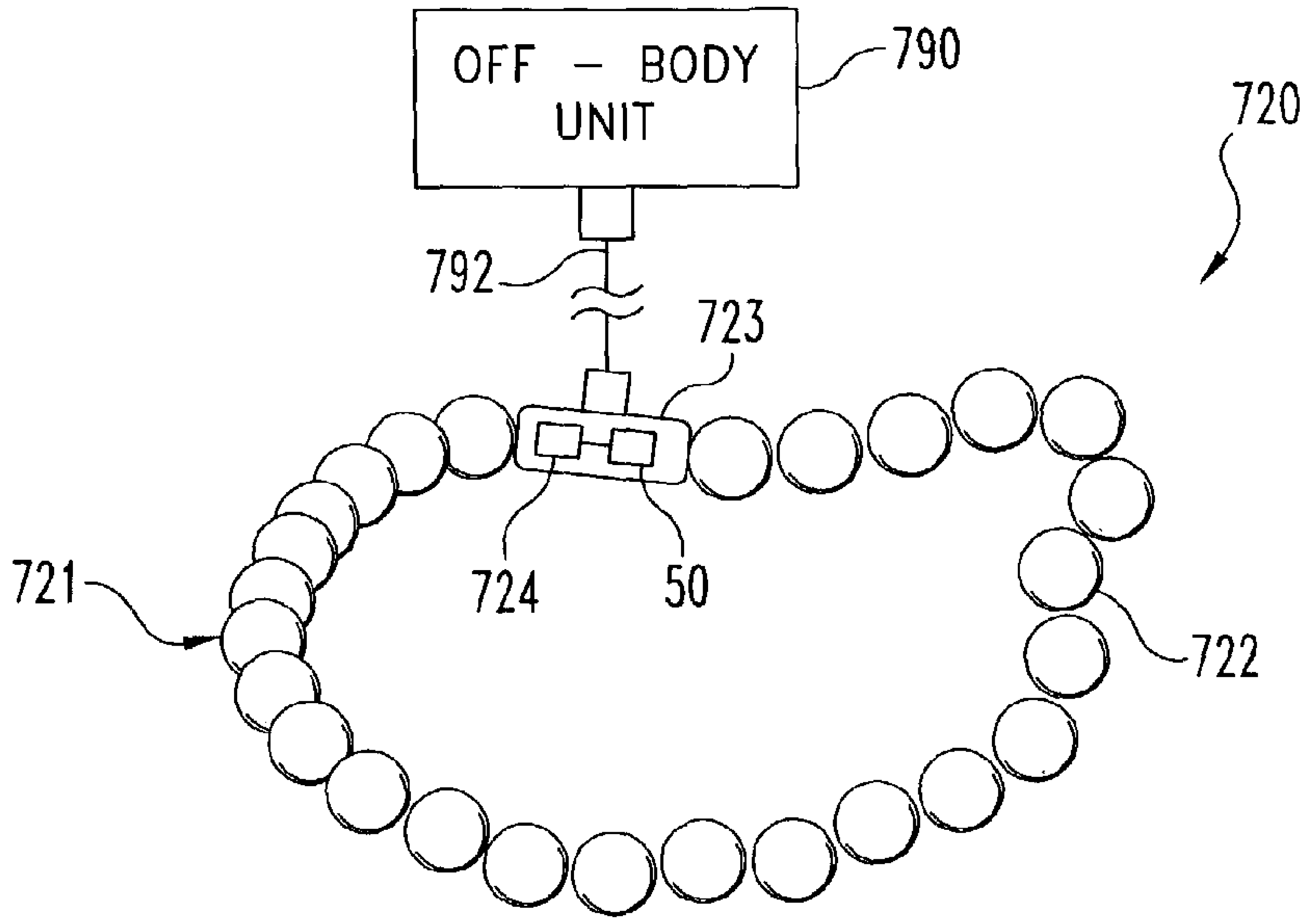
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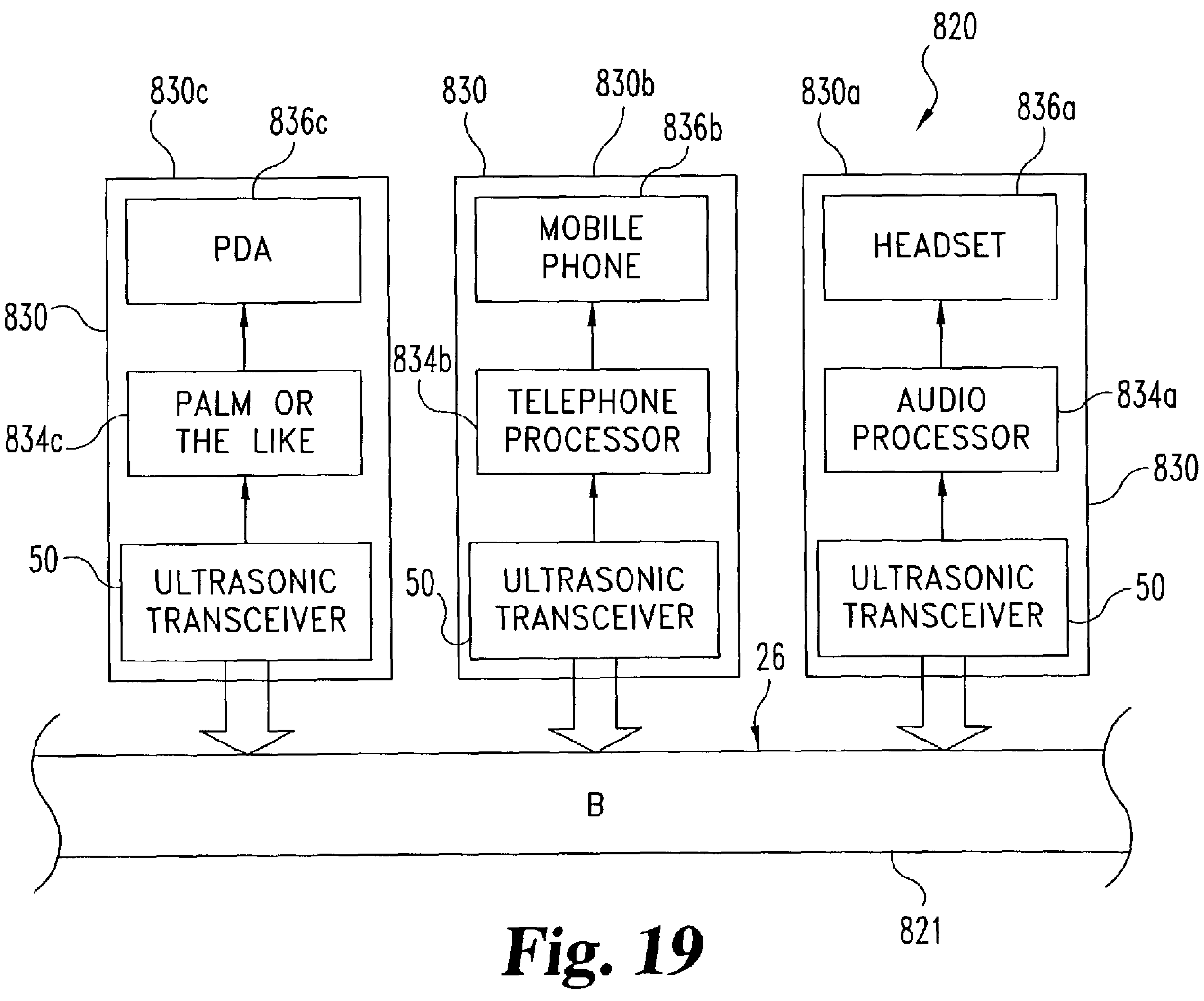
Fig. 18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830b
836b
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PDA
MOBILE PHONE
HEADSET
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PALM OR THE LIKE
TELEPHONE PROCESSOR
AUDIO PROCESSOR
834a
834c
830
50
ULTRASONIC TRANSCEIVER
50
ULTRASONIC TRANSCEIVER
ULTRASONIC TRANSCEIVER
50
26
B
821

Fig. 19

INTRABODY COMMUNICATION WITH ULTRASOUND

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related to International Patent Application Number PCT/US01/15047 filed on May 10, 2001; International Patent Application Number PCT/US01/14945 filed on May 9, 2001; U.S. patent application Ser. No. 09/805,233 filed on Mar. 13, 2001; U.S. patent application Ser. No. 09/568,435 filed on May 10, 2000; U.S. patent application Ser. No. 09/568,430 filed on May 10, 2000; International Patent Application Number PCT/US99/26965 filed on Nov. 16, 1999; and U.S. Pat. No. 6,222,927 B1; all of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates to communications, and more particularly, but not exclusively, relates to communication with ultrasound transcutaneously transmitted between devices carried on or implanted in the human body.

Various approaches have been suggested to communicate between electronic devices carried on a person's body. Of particular interest is the communication between components of a hearing aid system. Such systems frequently include a signal processor, one or more microphone units, and/or hearing stimulus units spaced apart form one another relative to a user's body. U.S. patent application Ser. No. 09/805,233 filed on Mar. 13, 2001; Ser. No. 09/568,435 filed on May 10, 2000, and Ser. No. 09/568,430 filed on May 10, 2000; and U.S. Pat. No. 6,222,927 B1 are cited as further sources concerning various hearing systems.

Interconnecting body-carried components for hearing systems and other applications by wires or cables to facilitate electrical or optical communication between the components is generally undesirable. Indeed, wireless Radio Frequency (RF) communications through the atmosphere have been suggested to address this shortcoming. However, communication through the transmission of electromagnetic signals in this manner also has certain drawbacks, such as the potential for interference by stray signals, the difficulty of incorporating the necessary transmission and reception circuits into a device of a size that can be comfortably worn by the user, undesirable power consumption, and/or a high degree of signal attenuation. Accordingly, there is an ongoing demand for further contributions in this area of technology.

SUMMARY OF THE INVENTION

One embodiment of the present invention includes a unique communication system. Other embodiments include unique methods, systems, devices, and apparatus for intrabody communication utilizing ultrasound. As used herein, "sound" and "sonic" refer to an acoustic wave or waves with a frequency less than or equal to 20,000 Hertz (Hz), and "ultrasound" and "ultrasonic" refer to an acoustic wave or waves with a frequency greater than 20,000 Hz.

A further embodiment includes at least two system units operable to be placed on the body of a user. These units each include an ultrasonic transmitter/receiver arrangement. This arrangement includes one or more ultrasonic transducers. These transducers are effective to acoustically couple to skin of the user's body to provide bidirectional point-to-point communication between the units with information-containing ultrasonic signals. In one form, the units are arranged to provide a hearing system with at least one of the units being operatively arranged to stimulate hearing of the user.

Still another embodiment of the present invention includes a hearing system that has an external module arranged to be carried on the body of a user and an implantable module to be at least partially implanted in the body of the user. The external module includes at least one microphone to detect sound and a transmitter to send ultrasonic signals containing information representative of detected acoustic signals when the external module is acoustically coupled to the user's skin. The implantable module includes a receiver and a hearing stimulation arrangement. The receiver receives the ultrasonic signals along an ultrasonic communication link through at least a portion of the body of the user between the external module and the implantable module when the implantable module is at least partially implanted in the body of the user. The hearing stimulation arrangement is responsive to the ultrasonic signals received by the receiver to stimulate hearing of the user in correspondence to the detected sound.

Yet a further embodiment includes a hearing system with an implantable module at least partially implantable in a user's body and at least one external module selected from the group consisting of a programming unit, a remote control, a microphone, and a signal processing device. The implantable module also includes at least one microphone to detect sound, an audio signal processor, and a hearing stimulation arrangement to stimulate hearing in response to the sound detected with the microphone. The external module includes a transmitter for sending information in the form of ultrasonic signals to the implantable module via a transcutaneous ultrasonic communication link through at least a portion of the user's body between the external module and the implantable module. The transmitter is effective to modulate the ultrasonic signals with a carrier frequency in a range between 100 kiloHertz (kHz) and 10 MegaHertz (MHz). The implantable module receives the ultrasonic signals and selectively adjusts operation in response thereto.

A still further embodiment includes: providing a communication system carried by a user's body that includes a first device and a second device; acoustically coupling the first device to a first skin region of the user's body and the second device to a second skin region of the user's body; and bidirectionally communicating between the first and second devices by transmitting ultrasound through at least a portion of the user's body between the first device and the second device.

Yet a further embodiment includes: providing a communication system carried by a user's body, the system including a first device with a sound sensor and a second device; detecting sound with the sensor; generating an ultrasound signal representative of the sound with the first device; and transmitting the ultrasound signal through at least a portion of the user's body from the first device to the second device.

In another embodiment, a hearing system is provided including a first device spaced apart from a second device. The first and second devices are coupled to a user's body with at least one of the first device and second device being acoustically coupled to skin. Two-way communication is performed between the first and second devices through bidirectional transmission of ultrasound signals through at least a portion of the user's body between the first device and second device.

Another embodiment includes: providing a hearing system including a first device spaced apart from a second device; acoustically coupling the first device and the second to a user's body; and performing two-way communication between the first device and the second device through bidirectional transmission of ultrasound signals through at least a portion of the user's body between the first device and the second device. In one form, the ultrasound signals are provided with a carrier frequency in a range between 100 kHz and 10 MHz.

In another embodiment, a hearing system is provided including a first device and second device that are coupled to a user's body in a spaced-apart relationship. An information-carrying ultrasound signal is transmitted from the first device to the second device over a path along a distance of which at least one-half is through non-bony, soft tissue of the user's body. The ultrasound signal is received with the second device and an output is generated based on information determined at least in part from the ultrasound signal.

Further forms, embodiments, objects, features, aspects, benefits, and advantages of the present invention shall become apparent from the detailed drawings and descriptions provided herein.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following figures, like reference numerals represent like features. In some cases, the figures or selected features thereof are not drawn to scale to enhance clarity.

FIG. **1** is a diagrammatic view of an intrabody communication system of a first type as worn by a user.

FIG. **2** is a side view of a portion of the system of FIG. **1**.

FIG. **3** is a diagrammatic cross-sectional view of a portion of the system of FIG. **1** relative to structures of the user's ear.

FIG. **4** is a schematic view of various hearing system devices utilized in the system of FIG. **1**.

FIGS. **5** and **6** are schematic views of alternative transmitter/receiver arrangements for the ultrasonic transceiver included in the hearing system devices of FIG. **4**.

FIG. **7** is a schematic view of an intrabody communication system of a second type.

FIG. **8** is a diagrammatic view of an intrabody communication system of a third type as worn by a user.

FIG. **9** is a schematic view of hearing system devices utilized in the system of FIG. **8**.

FIG. **10** is a view of an in-the-ear canal hearing system device.

FIGS. **11-13** are alternative sectional views of the device shown in FIG. **10**.

FIG. **14** is a partial diagrammatic view of a further type of hearing system device for intrabody communication.

FIG. **15** is a partial diagrammatic view of another type of hearing system device for intrabody communication.

FIG. **16** is a partially diagrammatic, perspective view of still another type of hearing system device for intrabody communication.

FIG. **17** is a partial diagrammatic view of yet another type of hearing system device for intrabody communication.

FIG. **18** is a partial diagrammatic view of a further hearing system device for intrabody communication.

FIG. **19** is a schematic view of an intrabody communication system of a fourth type.

DESCRIPTION OF SELECTED EMBODIMENTS

While the present invention may be embodied in many different forms, for the purpose of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the invention relates.

One embodiment of the present invention is directed to an intrabody communication system that utilizes ultrasound. In one form, this system is utilized to provide a body area network to communicate between various body-worn devices, such as a headset with one or more earphones and/or one or more microphones, a Personal Digital Assistant (PDA), a mobile phone, and the like. In another form, this system is utilized to communicate between components of a hearing system arrangement, such as that depicted in FIGS. **1-4**.

Referring to FIGS. **1-4**, intrabody communication system **20** is in the form of a hearing system **21** with hearing system units **30***a*, **30***b*, **30***c*, and **30***d* (collectively designated modules **30**). System **20** communicates operational information between modules **30** by utilizing at least a portion of body B of the user as an ultrasonic transmission line. Hearing system units **30***a*, **30***b*, and **30***c* are external to body B while unit **30***d* is of an implantable type shown internal to body B (see, for example, FIG. **1** and FIG. **3**). External hearing system units **30***a* and **30***b* are each in the form of a Behind-The-Ear (BTE) device **31** with respect to ears E1 and E2 of body B. Devices **31** each include sound sensor **32** in the form of a microphone **32***a*. Microphone **32***a* can be of an omnidirectional type, or of a directional type such as those with a cardioid, hypercardioid, or FIG. **8** directional pattern to name just a few. Devices **31** also each include a signal processing arrangement **34** coupled to sensor **32** to receive signals therefrom (see, for example FIGS. **2** and **4**). In one form, signal processing arrangement **34** includes circuitry to receive electrical signals from sensor **32** representative of detected sound. For this form, signal processing arrangement **34** further includes circuitry to condition, filter, and/or amplify the received signals; and as appropriate, convert the received signals into a desired format—such as conversion from an analog-to-digital format. Signal processing arrangement **34** can include one or more digital signal processors responsive to the received electric signals in a digital format and/or control signals to modify its operation. Electrical power for device **31** can be provided in the form of an electrochemical cell or battery and/or a different source as would occur to those skilled in the art.

Devices **31** each also include ultrasonic transceiver **50** in contact with skin **26** of body B. As used herein, "transceiver" refers broadly to any device having a capability to transmit and receive information. Referring to FIGS. **5** and **6**, two alternative transmitter/receiver arrangements **50***a* and **50***b* for ultrasonic transceiver **50** are illustrated. Transmitter/receiver arrangement **50***a* includes ultrasonic transducers **51***a* and **51***b* each having a respective transducer face **52***a* and **52***b* arranged to be acoustically coupled to body B. To that end, face **52***a*, **52***b* is comprised of at least a portion of an outer surface of an enclosure that houses arrangement **50***a* and/or is acoustically coupled to such outer surface. For external applications, coupling to body B can be through direct contact of transducer face **52***a*, **52***b* with skin **26** of body B; where transducer face **52***a*, **52***b* is shaped and sized with respect to the coupling area of body B to reduce air gap formation between face **52***a*, **52***b* and body B so that an unacceptable level of ultrasonic signal attenuation does not occur. Additionally or alternatively, a conformal interface material, such as an adhesive, a gel, a liquid, or other type of material could be used to provide a desired acoustic coupling. For subcutaneous applications, transducer acoustic coupling can be directly to bone, cartilage, or such other tissue as would occur to those skilled in the art. An adhesive or other mounting technique to hold the transducer in a desired position and contact relationship could be utilized to implement such subcutaneous applications.

Transducers **51***a* and **51***b* are coupled to transmitter (TXR) **53** and receiver (RXR) **54**, respectively. Transmitter **53** and receiver **54** are coupled to codec **55**. Codec **55** includes encoder **56** and decoder **57**. Codec **55** is arranged to communicate externally with signal processing devices such as signal processing arrangement **34** of device **31**. Typically, such communications are in a digital format; however, other formats could be additionally or alternatively utilized.

Codec **55** receives information-containing signals from an external source, such as signal processing arrangement **34**, and encodes these signals into a desired transmission format with encoder **56**. By way of nonlimiting example for digitally encoded formats, an Amplitude Shift Keying (ASK), a Frequency Shift Keying (FSK), a Phase Shift Keying (PSK), a Pulse Width Modulation (PWM), or a Pulse Amplitude Modulation (PAM) technique could be utilized, just to name a few. An encoded signal is provided from codec **55** to transmitter **53** for conversion to a modulated electronic output. Transmitter **53** includes a drive amplifier to provide an output signal of a desired level and impedance. This modulated signal output from transmitter **53** is operable to stimulate transducer **51***a* to generate a corresponding modulated ultrasonic signal that can be transmitted via face **52***a* through body B.

Transducer **51***b* is arranged to generate an electrical output signal in response to detection of a suitably configured ultrasound signal received via face **52***b* from body B. This electrical output signal from transducer **52***b* is received by receiver **54** for demodulation. Receiver **54** includes a sense amplifier to assist in such operations. The corresponding demodulated signal output by receiver **54** is provided in an electronic format to codec **55**. Decoder **57** of codec **55** decodes the signal from receiver **54**, as appropriate for its expected format. Codec **55** then provides a signal externally for use by external signal processing equipment, such as signal processing arrangement **34**. For transmitter/receiver arrangement **50***a*, transducers **51***a* and **51***b* can be dedicated to transmitter **53** and receiver **54**, respectively; however, in other arrangements, one or more ultrasonic transducers can be utilized for both transmitter and receiver operations.

For example, transmitter/receiver arrangement **50***b* of FIG. **6** includes transducer **51***c* with face **52***c*. Face **52***c* is arranged to comprise at least a portion of an outer surface of an enclosure for arrangement **50***b* and/or is acoustically coupled to such surface. Face **52***c* can be acoustically coupled to body B as described in connection with faces **52***a*, **52***b* of transmitter/receiver arrangement **50***a*. Transducer **51***c* is coupled to transmitter **53** and receiver **54**, which operate in a manner previously described in connection with like reference numerals of FIG. **5**. Typically, transducer **51***c* is time-shared on a periodic or aperiodic basis between an ultrasound signal transmit mode and an ultrasound signal receive mode, correspondingly utilizing transmitter **53** and receiver **50** of arrangement **50***b*. In one embodiment of arrangement **50***b*, transmit and receive modes are time-multiplexed in a predefined manner. In other embodiments, changes between receive and transmit modes may be upon demand or be performed in accordance with such other techniques as would occur to those skilled in the art. In still other embodiments, different carrier frequencies and/or modulation techniques can be utilized; such that ultrasonic signals can be transmitted and received with a single transducer in a virtually simultaneous fashion without unacceptable levels of interference between the modes.

While transmitter **53**, receiver **54**, codec **55**, encoder **56**, and decoder **57** have been shown as separate operational components to enhance understanding, it should be appreciated that some or all of these operations could be provided by common circuitry and/or components. In one such form, a custom signal processing integrated circuit device can be provided to perform many, if not all, of these operations with little, if any, support circuitry.

Returning to FIGS. **1-4**, system **20** also includes unit **30***c* that provides user control in off-body communication in the form of a signal processing and control device **40**. Device **40** is worn by the user with a wrist strap or wrist band **41**. Indeed, device **40** can be integrated into a wristwatch or made to appear as one. The WATCHPILOT provided by PHONAK AG, which has a business address of Laubisrütistrasse 28, 8712 Stäfa, Switzerland, could be adapted to such use. Device **40** includes user control **42** arranged to provide input through one or more push buttons, rotary dials, switches, or the like. Device **40** also includes indicator **43** to provide user-observable output. Indicator **43** is typically in the form of a Liquid Crystal Display (LCD) or Light Emitting Diode (LED) display, but can be differently configured as would occur to those skilled in the art.

Device **40** also includes off-body communication interface **45**. Interface **45** includes a wireless off-body Radio Frequency (RF) transmitter (TXR) **45***a* and receiver (RXR) **45***b*, which collectively provide RF transceiver **45***c*. Transceiver **45***c* is coupled to antenna **46**. Interface **45** is configured to wirelessly and bidirectionally communicate with off-body device **90** via antenna **92** of device **90**. In one form, this RF communication is performed in accordance with a BLUETOOTH or AUTOCOM standard, and/or a MICROLINK or MLX standard from PHONAK AG. Alternatively or additionally, off-body interface **45** can be arranged for communication by an electrically wired connection and/or optical fiber connection provided with appropriate cabling to off-body device **90**. In still other embodiments, ultrasonic transmission through the air and/or infrared (IR) communication techniques could be used in addition or as an alternative.

Device **40** further includes signal processing arrangement **44** coupled to control **42**, indicator **43**, and interface **45**. In one form, signal processing arrangement **44** includes electrical circuitry to receive and process user inputs from control **42** and generate information for output via indicator **43**. Further, signal processing arrangement **44** includes circuitry to communicate via interface **45**. Device **40** also includes ultrasonic transceiver **50**. Signal processing arrangement **44** is operatively coupled to ultrasonic transceiver **50**. Transceiver **50** is in contact with skin **26** of the user's body B, and can include one of the arrangements **50***a* or **50***b* previously described in connection with FIGS. **5** and **6**, respectively; or be of such different arrangement as would occur to those skilled in the art. In one nonlimiting form, signal processing arrangement **44** includes one or more processors with programming to facilitate Input and/or Output (I/O) via control **42**, indicator **43**, interface **45**, transceiver **50**, and perform any desired data modifications, conversions, storage, or the like; and includes any signal conditioners, filters, format converters (such as analog-to-digital and/or digital-to-analog types), amplifiers, power sources, or the like to implement desired operations as would occur to those skilled in the art.

Hearing system unit **30***d* is illustrated as being implanted within body B in the vicinity of structures associated with ear E1. Hearing system unit **30***d* includes implanted hearing device **60** which includes ultrasonic transceiver **50** previously described in connection with device **31** and device **40**. Referring specifically to FIGS. **3** and **4**, device **60** includes signal processing arrangement **64** operatively coupled to ultrasonic transceiver **50**, both of which are encapsulated in the enclosure **61**. Enclosure **61** is implanted in the mastoid region of ear E**1**. In one form, enclosure **61** is made from titanium, a ceramic material, or such other body-compatible material as would occur to those skilled in the art.

Device **60** also includes hearing stimulation arrangement **70** coupled to signal processing arrangement **64** via one or more wires or cables from enclosure **61**. Hearing stimulation arrangement **70** includes middle ear actuator **72** coupled to the middle ear region in the vicinity of the auditory canal. Hearing stimulation apparatus **70** also includes an electromechanical intracochlear actuator **74**, such as a bone conduction cochlear stimulator coupled to the small bones of the ear (malleus, incus, and/or stapes), and intracochlear stimulation electrodes **76** implanted within the cochlea. However, it should be understood that more or fewer hearing stimulation apparatus, or perhaps only one of these hearing stimulators could be used in other embodiments. Device **60** further includes auditory canal microphone **80** coupled to signal processing arrangement **64** via cabling. Microphone **80** can be used to detect acoustic signals in addition to or in lieu of sensors **32** to enhance natural sound perception of the user.

Referring to FIGS. **1**-**6**, certain operational aspects of system **20** for aiding hearing of the user are next described. Modules **30** are arranged to bidirectionally communicate using at least a portion of body B between communicating units **30***a*, **30***b*, **30***c* and **30***d* as an ultrasonic communication link; or stated differently, as an ultrasonic transmission line. Such two-way ultrasonic communication is represented by the double-headed arrows in FIG. **4** between symbolically illustrated portions of body B in contact with ultrasonic transceivers **50** of modules **30**. Accordingly, a Body Area Network (BAN) is implemented with system **20**.

In one mode of operation, devices **31** are each mounted to the pinna of a respective ear E**1** or E**2**, providing a spaced-apart sensor relationship for detecting sound. Inputs from spaced-apart sensors **32** can be processed to provide a corresponding hearing stimulus to the user via device **60**. Such processing could be performed with the signal processing arrangement of one or more of modules **30**, optionally utilizing ultrasonic communication capabilities to transmit information between modules **30** to perform remote or distributed processing with the signal processing arrangements, as required. In one form, at least some processing tasks are distributed among two or more processing units to perform pipelined and/or parallel processing operations. Collectively, system **20** can be arranged to perform adaptive beamforming and/or binaural processing routines for a hearing aid as described, for example, in International Patent Applications Nos. PCT/US01/15047, PCT/US01/14945, or PCT/US99/26965; U.S. patent application Ser. Nos. 09/805,233, 09/568,435, or 09/568,430; and/or U.S. Pat. No. 6,222,927 B1. Alternatively or additionally, other processing techniques can be used to provide a desired type of hearing stimulus.

In such implementations, device **40** can be used to provide the user means for remotely controlling selected aspects of system performance, such as hearing system volume, sound filtering, sensitivity, a sound detection beamwidth or direction, and the like through control **42**. Indicator **43** can be used to provide the user selected visual output regarding system user settings and/or one or more other performance parameters, such as battery/power status of one or more modules **30**, and the like.

Off-body interface **45** can be arranged to receive information from off-body device **90**. Such information can include remote audio input to the user from a Public Address System (PAS), telephonic communication link, one or more remote microphones, an entertainment source such as a radio, television, MP3 player, tape player, CD player, etc. and/or a different type of audio satellite, just to name a few. Alternatively or additionally, off-body device **90** can provide data and/or parametric values used in the operation of system **20**. Interface **45** can also be used in conjunction with device **90** to perform testing of one or more modules **30** and/or of system **20** collectively; communicate system or module diagnosis; and/or system/module performance data. Further, where applicable, off-body **90** and interface **45** can be used to add or modify software utilized by any of modules **30**. For any information communicated via interface **45**, it should be understood that ultrasonic communication can be used to transmit/receive information with respect to modules **30** other than module **30***c*. In addition or as an alternative, interface **45** can communicate through another wireless technique and/or by cable connection.

It should be understood that point-to-point ultrasonic communication between external hearing system units **30***a*, **30***b*, and **30***c* from one to the next corresponds to a skin-to-skin ultrasonic transmission. In contrast, point-to-point ultrasonic communication with unit **30***d* occurs transcutaneously with one or more of units **30***a*, **30***b* and **30***c*. For example, as illustrated in FIG. **3**, ultrasonic transceiver **50** of unit **30***a* is arranged to be in close proximity to ultrasonic transceiver **50** of unit **30***d* to facilitate bidirectional communications therebetween. Likewise, one-way or two-way ultrasound-conveyed information can be directly communicated between unit **30***d* and one more of units **30***b* and **30***c*; and/or can be communicated via unit **30***a*. Indeed, in alternative embodiments one or more of units **30***a*, **30***b*, **30***c*, and/or **30***d* may include only the capability to transmit or only the capability to receive ultrasonic signals as desired for the particular arrangement.

It has been surprisingly found that ultrasound communications based on a frequency selected from a range between 100 kHz and 10 MHz can be used to communicate through the human body at a relatively high bandwidth without undesirable levels of attenuation in soft tissue. Accordingly, when such performance is desired, a preferred ultrasound carrier frequency is selected from the range between 100 kHz and 10 MHz. In a more preferred embodiment, an ultrasonic carrier frequency range of about 500 MHz to about 2 MHz is utilized. In terms of digitally encoded information, a bandwidth from about 300 kilobits/second (kb/s) through about 500 kb/s can be utilized for an ultrasound carrier having a frequency in this range. For either the 100 kHz-10 MHz or 500 kHz-2 MHz range, it has been found that higher frequency-transmissions are typically more effective for shorter communication paths through body B, and lower frequency transmissions are typically more effective for relatively longer communication paths through body B. With respect to system **20**, one nonlimiting example of a relatively shorter communication path is between units **30***a* and **30***d*; and one nonlimiting example of a relatively longer communication path is between units **30***a* and **30***c*. Nonetheless, in other embodiments, the communication frequency may be determined independent of the transmission distance through body B, may be uniform regardless of distance, or may be differently determined as would occur to those skilled in the art.

In one embodiment, an ultrasound carrier is used to communicate information along a path having a distance at least half of which is through nonbony, soft tissue. For instance, communication between unit **30***c* and **30***d* can take place directly along a path through soft tissue in the cranium of the user. In one alternative embodiment, some or all of the components and/or corresponding functionality of unit **30***c* are included in one or both units **30***a*, **30***b*; and unit **30***c* is not present. In relation to system **20**, this alternative can provide a basis for a relatively greater number of communications through soft tissue of the user's head. In still another alternative embodiment, unit **30***c* and unit **30***a* or **30***b* are not present. For this alternative, the remaining unit **30***a* or **30***b* can include some or all of the components and/or corresponding functionality of the one or more units not present.

In one experimental example, ultrasonic signals with a carrier frequency in the 500 kHz to 2 MHz range were transmitted from one mastoid to the other of a human subject with an attenuation of no more than about 20 deciBels (dB). At least one half of the distance traveled by this communication was through soft, non-bony tissue of the human subject's head. Compared to standard RF body area transmission techniques, the level of attenuation of ultrasonically communicated signals in the 500 kHz-2 MHz range according to the present invention can be several orders of magnitude better. Further, for this ultrasonic communication approach, power consumption on the order of about one milliWatt (mW) is made possible compared to at least ten times that for typical RF techniques. Also, a bandwidth of at least 300 kbits/second can be provided with an ultrasonic carrier frequency in the 1-2 MHz range.

FIG. **7** illustrates intrabody communication system **120** of another embodiment of the present invention; where like reference numerals refer to like features. System **120** includes a number of hearing system units **130** more specifically designated external processing device **131**, external remote control device **140**, external programming device **150**, and internal hearing device **160**. Device **160** is at least partially implantable in body B of a user of system **120**. Each hearing system unit **130** includes an ultrasonic transceiver **50** of the type previously described to communicate among units **130** utilizing at least a portion of body B as an ultrasonic signal communication link. Such communications can be bidirectional in nature as symbolized by the double-headed arrows between portions of body B presented in FIG. **7**.

Device **131** includes an external signal processor **134** operatively coupled to communicate with other units **130** through ultrasonic transceiver **50** of device **131**. Signal processor **134** is operatively coupled to one or more external sensors **132** arranged to detect sound. Sensors **132** can be in the form of a microphone **32***a* previously described, but can alternatively or additionally be provided as a different type of sound or acoustic detector. Device **131** also includes wireless transceiver **136** which is coupled to signal processor **134**. Wireless transceiver **136** operates through a standard RF communication technique to transmit to and/or receive information from a remote source, as described in connection with interface **45** and device **90**. Device **131** also includes cable interface/connection **138** to receive/transmit information in an electrical and/or optical format via cabling. Such information can include some or all of the type described in connection with interface **45** and device **90** of system **20**. Device **131** can be in the form of one or more Behind-The-Ear (BTE) devices, In-The-Canal (ITC) of the ear devices, or otherwise worn on body B with acoustic coupling to skin **26** of body B as previously described in connection with system **20**.

Device **140** provides remote control **142** coupled to ultrasonic transceiver **50**. Remote control **142** can be operated by a user and/or service provider to adjust operation of one or more aspects of system **120**. In one form, device **140** is of a portable type that is temporarily placed in contact with skin **26** of body B to perform its operations. In other embodiments, device **140** is body-worn with a wrist band, a device appearing as jewelry, a BTE device, an ITC device, or the like. Device **140** can be arranged to receive confirmation of changes in settings or other transmission to any of units **130** from device **140**. In other embodiments, device **140** can be arranged to provide for one-way communication—transmitting to other units **130** only.

Device **150** includes system programmer **152** operatively coupled to ultrasonic transceiver **50** of device **150**. Collectively, programmer **152** and the coupled ultrasonic transceiver **50** of device **150** communicate via ultrasonic signals through a portion of body B to add to or modify programming associated with one or more of the other units **130**. Device **150** can be of a portable type that is temporarily placed in contact with skin **26** of body B by a user or service provider only to perform programming changes as needed, or can be a more permanent body-worn type implemented with a wrist band, a device appearing as jewelry, a BTE device, an ITC device, or the like. Likewise, device **150** can be of a "transmit only" type or a two-way communication type regarding ultrasonic transmissions with other units **130**. In alternative embodiments, at least two of devices **131**, **140**, and **150** are combined in a single unit (not shown).

Device **160** can be of a type comparable to device **60** of system **20**. Device **160** includes internal signal processor **164**. Internal signal processor **164** is coupled to ultrasonic transceiver **50** of device **160** to selectively provide for communication therewith. Processor **164** is also coupled to hearing stimulation apparatus **170** of device **160**. Hearing stimulation apparatus **170** can include one or more of the hearing stimulators of arrangement **70** and/or one or more different hearing stimulator types. Device **160** also includes internal microphone **180** that can be of a subcutaneous type or located in the auditory canal. Collectively, units **130** can operate to perform standard signal processing to enhance hearing of a user of system **120** in the manner previously described in connection with system **20**.

FIGS. **8** and **9** illustrate intrabody communication system **220** of another embodiment of the present invention; where like reference numerals refer to like features. System **220** includes hearing system units **230**. Hearing system units **230** are more specifically designated ear canal device **231**, remote control and interface device **240**, and programming device **150** (only shown in FIG. **9**). Each of units **230** includes an ultrasonic transceiver **50** to provide bidirectional communication that utilizes at least a portion of body B as an ultrasonic signal communication link as previously described. Device **231** includes acoustic sensor **232**. Sensor **232** can be a microphone or such other sound detecting sensor type as would occur to those skilled in the art. Sensor **232** is coupled to signal processor **234** which processes received signals to generate a corresponding output to hearing stimulator **236** in the form of ear canal loudspeaker **238**. Processor **234** can be arranged to perform desired processing of signals received with sensor **232** and generate a corresponding hearing stimulus via stimulator **236** in a manner common to standard ITC devices.

Device **240**, shown in the form of a body-worn wrist band **41** (see FIG. **8**), can include user control **42** to control various operations and settings of device **231** and user viewable indicator **43** to display settings or other information for the user as described in connection with system **20**. Device **240** further includes off-body interface **246** to provide for one-way or two-way communication of information with a remote device as described in connection with interface **45** and off-body device **90** of system **20**. Control **42**, indicator **43**, and interface **246** are coupled to signal processor **244** which is responsive to suitable inputs and generates corresponding outputs for these components. Device **240** operates in a manner comparable to device **40** of system **20** to provide user control and information exchange relative to device **231**. It should be understood that signal processing relative to sound detected with sensor **232** can be performed by processor **244** via ultrasonic communication in addition to or as an alternative to processing with processor **234**. In other embodiments, device **240** can include one or more acoustic sensors in addition to or as an alternative to sensor **232** of device **231**. Collectively, devices **231** and **240** can operate in a standard manner to enhance hearing of a user of system **220** with regard to acoustic inputs received via sensor **232** and/or audio inputs (if any) received via interface **246**.

Device **150** (not shown in FIG. **8**) is of the type described in connection with system **120**, being operable to add to and/or modify programming of one or more of processors **234**, **244**. Correspondingly, device **150** of system **220** can be temporarily utilized as needed to change programming of one or more other units **230** or of a more permanent body-worn type. Alternatively or additionally, unit **150** can be combined with one or more other units **230** in other embodiments.

FIG. **10** illustrates a hearing system unit **280** in the form of an In-The-Canal (ITC) of the ear device **281**. Device **281** includes case **282** enclosing operational components, such as those described in connection with device **231**; where like reference numerals refer to like features. Referring to the sectional views of FIGS. **11-13**, alternative ultrasonic arrangements are illustrated for a representative cross-section of device **281** along line A-A. In FIG. **11**, a coating on the outer surface **282***a* of case **282** with an ultrasonic transduction material **250***a* defines, at least in part, the corresponding ultrasonic transducer **50**. Material **250***a* can be of a piezoelectric or ferroelectric type or such different type as would occur to those skilled in the art. In FIG. **12**, coating **250***b* on an inner surface **282***b* of case **282** with an appropriate ultrasonic transduction material, such as a piezoelectric or ferroelectric provides the corresponding ultrasonic transducer **50**. In FIG. **13**, a chip **250***c* of ultrasonic transduction material, such as a piezoelectric or ferroelectric, is mounted inside case **282** and is in acoustical contact with case **282** to provide the corresponding ultrasonic transducer **50**. In other arrangements, two or more of these approaches could be combined, and/or one or more of these approaches could be used to provide a transducer for an external or internal hearing system unit or other intrabody communication device.

FIGS. **14** and **15** illustrate two different types of earlobe (EL) worn devices **320***a*, **320***b* each configured in the form of an earring **321***a*, **321***b*. Each device **320***a* and **320***b* includes an earring case **322** enclosing a signal processor and coupled microphones collectively designated by reference numeral **324**, a power source in the form of battery **326**, and an ultrasonic transceiver **50** coupled to the signal processor and microphones **324**. For device **320***a*, case **322** is connected to post **330** which is configured to extend through an aperture (such as results from a piercing) of earlobe EL to be secured by a push-on fixation device **332** of the type commonly used with earrings. In FIG. **14**, earlobe EL is shown in section to more clearly illustrate post **330**. For device **320***b*, case **322** is coupled to clip **340** by spring **342** to provide a compressive grip around earlobe EL. Devices **320***a*, **320***b* can be utilized in place of a BTE type of device, or other type of external hearing system unit previously described. In one such alternative, an earring clip arrangement of device **320***b* is connected to earlobe EL to program a hearing system, having a cable connection to an off-body programmer. When the programming operation is complete, the earring clip is removed. In still other embodiments, an earring is utilized to provide an external microphone for temporary or nominal use.

Referring to FIG. **16**, hearing system **520** includes eye glass frame **521**. Frame **521** includes articulating earpieces **522***a*, **522***b*. System **520** also has sensors **32** positioned proximate to the temple hinges of frame **521**. Ear piece **522***b* includes processor **534** operatively coupled to sensors **32**, and ultrasonic transceiver **50** operatively coupled to processor **534** to collectively provide a hearing system device operationally comparable to the two devices **31** of system **20**. A power source in the form of an electrochemical cell or battery or other type is also included (not shown). In other arrangements, different operations, and/or combinations of previously described embodiments could be incorporated into eye glass frame **521** using techniques known to those skilled in the art.

FIG. **17** illustrates ear E**2** of body B having hearing system ear button **630** coupled behind ear E**2**. Ear button **630** can be held in place by an adhesive, a mechanical clip, a magnetic arrangement, and/or in a different manner as would occur to those skilled in the art. Ear button **630** can include a signal processor **634** and ultrasonic transceiver **50** of the type previously described. A power source in the form of an electrochemical cell or battery, or other type of power source is also included, but not shown to preserve clarity. Ear button **630** can be used to relay information unidirectionally or bidirectionally from other hearing system units and/or can include microphones to provide for communications with implanted devices. In one embodiment, ear button **630** can be used as a substitute for device **31**, device **231**, device **320***a*, device **320***b*, a combination of these, or such different hearing system unit configuration as would occur to those skilled in the art.

Referring to FIG. **18**, system **720** is illustrated in which intrabody communication device **721** is provided in the form of a bracelet **722** with case **723**. Case **723** houses signal processor **724** and ultrasonic transceiver **50**, which are coupled together. A power source in the form of an electrochemical cell or battery, or other type of power source is also enclosed, but is not shown to preserve clarity. Processing arrangement **724** further includes an off-body interface for communicating with off-body unit **790** via cable **792**. Alternatively or additionally, processing arrangement **724** can be configured to include a wireless off-body communication arrangement. System **720** can be used to incorporate any of the external units previously described in connection with systems **20**, **120**, and/or **220**.

FIG. **19** illustrates intrabody communication system **820** including communication devices **830**. System **820** establishes a Body Area Network (BAN) **821** using ultrasonic communication between devices **830**. Typically, devices **830** are acoustically coupled to skin **26** of Body B. Communication devices **830** more specifically include headset unit **830***a*, mobile phone unit **830***b*, and Personal Digital Assistant (PDA) unit **830***c*. Units **830***a*, **830***b*, and **830***c* each include at least one ultrasonic transceiver **50** of the type previously described. Unit **830***a* further includes headset **836***a* coupled to audio processor **834***a* which is in turn coupled to the unit **830***a* ultrasonic transceiver **50** to selectively communicate with one or more devices **830**. Headset **836***a* includes one or more earphone loudspeakers and optionally at least one microphone. Audio processor **834***a* and/or unit **830***a* can optionally include an MP3 player, tape player, CD player, and/or a wireless radio or television receiver, just to name a few possibilities.

Unit **830***b* includes mobile phone **836***b* coupled to telephone processor **834***b* arranged to selectively communicate through ultrasonic transceiver **50** of unit **830***b*. Such communication could be to device **830***a* to provide aural input to the user and, when microphones are included in headset **836***a*, to receive sound input therefrom.

Unit **830***c* includes PDA **836***c* having an interface to an ultrasonic transceiver **50** of unit **830***c* to connect to body area network **821**. PDA **836***c* is coupled to transceiver **50** of device **830***c* via a PALM interface **834***c* or other appropriate arrangement. PDA **836***c* can communicate data to or from a remote source, such as the Internet or other computer network. Such computer network communication can be through wireless transmission with mobile phone **836***b* of unit **830***b*. In other embodiments, different devices could be used for intrabody communication based on bidirectional or unidirectional ultrasound transmission through BAN **821**. Indeed, one or more of the units of system **820** could be used in conjunction with one or more of the hearing system units of previously described embodiments, and/or utilizing short range RF techniques, such as BLUETOOTH, AUTOCOM, MICROLINK or MLX.

Any processor or signal processing arrangement referenced herein can be of a software or firmware programmable type, a dedicated hardwired device, or a combination of both. Further, such processor or arrangements can be comprised of one or more components and can include one or more Central Processing Units (CPUs). In one embodiment, unit processing is based on a digitally programmable, highly integrated semiconductor chip particularly suited for signal processing. In other embodiments, a more general purpose type of device or arrangement could be utilized. Further, any processor or processing arrangement referenced herein can include one or more memory devices and/or types of memory such as solid-state electronic memory, magnetic memory, or optical memory. Also, signal processing arrangements include any oscillators, control clocks, interfaces, signal conditioners, format converters, filters, limiters, power supplies, communication ports, or other types of arrangements/circuitry as would occur to those skilled in the art to implement the present invention. Indeed, such arrangements could be integrated along with one or more signal processors on a dedicated microelectronic device directed to one or more embodiments of the present invention.

Many other embodiments of the present invention are contemplated. For example, in some instances, only unidirectional communication would be used with one or more, or perhaps all of the units being of a dedicated receiver or transmitter type. Correspondingly, circuitry of ultrasonic transceiver **50** can be simplified in accordance with the dedicated nature of the communication for such units, with programming of associated processors or processing arrangements being altered as appropriate to the dedicated transmitter or receiver arrangement. In still other embodiments, a hybrid combination of ultrasonic communication with one or more other forms of wireless communication, such as RF or IR based communication and/or cabled electric or optic based communication, could be utilized. Indeed, ultrasonic communication through the air could be used in conjunction with ultrasonic communication through at least a portion of a user's body with or without one or more of these other transmission formats. Power sources for any of the units can be of a disposable and/or rechargeable type—such as a rechargeable battery. Indeed, for implantable devices, rechargeable battery sources can be utilized which can be recharged remotely through a transcutaneous inductive power transfer technique.

In further embodiments, one or more features of one of the systems, units, or devices described in connection with FIGS. **1-19** can be combined, duplicated, deleted, or modified relative to one or more other of these systems, units, and/or devices. The techniques of the present invention can be used in a wide array of hearing system applications including Cochlear Implants (CI), Middle Ear Implants (MEI), and/or Bone Anchored Hearing Aids (BAHA), to name just a few representative examples. Further, intrabody communication systems of the present invention can be used in a wide variety of medical systems that can be facilitated by a BAN, as well as other nonmedical BAN applications. By way of nonlimiting example, nonmedical BAN applications include, but are not limited to security communication systems, entertainment systems, and surveillance systems, to name only a few. In one alternative embodiment, underwater applications could use hydrophone in place of a microphone. In still other embodiments, one or more intrabody communication system units are of an in-front-of-the-ear type. In other embodiments, an earring device, BTE device, ITC device, eye glass frame device, bracelet device or the like is cabled to another device. Alternatively or additionally, one or more external microphones are cabled to such a device. Indeed, in one alternative embodiment a microphone close to one side of the user's head communicates ultrasonically through the user's head, at least partially by soft tissue conduction, to an implanted device close to the other side of the user's head and/or to an external device mounted on the other side of the user's head.

As used herein, communications via a cable connection to an interface can be through any standard protocol, including, but not limited to USB, RS232, RS422, etc. Likewise, wireless communications can be via any standard protocol appropriate to the medium and frequency range.

In another arrangement, one or more devices could be of a type that derives some or all of its power from other devices and/or parasitically from the user. For example, the movement of the user could be used to generate small amounts of usable power. Devices suitable for operation without an independent power source particularly include those that communicate with remote devices where power could be remotely supplied via the communication interface wirelessly (i.e. inductively) and/or through cabling. Communicating certain RF tag devices are nonlimiting examples of this kind of arrangement. In still other embodiments, a different power source and/or power supply source could be utilized as would occur to those skilled in the art.

A further embodiment of the present invention includes a bi-directional transcutaneous communication system for bi-directional point-to-point communication between at least two electronic system units placed on the body of a user, wherein each of the electronic system units incorporates an ultrasonic transmitter and an ultrasonic receiver, wherein the ultrasonic transmitters each include an ultrasonic transducer for converting electrical transmitter signals into information-containing ultrasonic signals, and wherein the ultrasonic receivers each include an ultrasonic transducer for converting information-containing ultrasonic signals into electrical receiver signals, the ultrasonic transducers, at least when in operation, being disposed in at least close proximity to the skin of the user for transmitting and receiving, respectively, ultrasonic signals utilizing the body of the user as an ultrasonic transmission line between the electronic system units. In one form, the communication system is directed to aiding hearing of a hearing impaired user. In another form, the communication system is utilized for entertainment and/or telephonic communication.

Still a further embodiment comprises a bi-directional transcutaneous communication system for bi-directional point-to-point communication between at least two electronic system units placed on the body of a user, wherein each of the electronic system units incorporates an ultrasonic transceiver, the transceiver including an ultrasonic transducer for converting, in a time sharing mode, electrical transmitter signals into information-containing ultrasonic signals and information-containing ultrasonic signals into electrical receiver signals, the ultrasonic transducer, at least when in operation, being disposed in at least close proximity to the skin of the user for transmitting and receiving, respectively, ultrasonic signals utilizing the body of the user as an ultrasonic transmission line between the electronic system units. In one form, the communication system is directed to aiding hearing of a hearing impaired user. In another form, the communication system is utilized for entertainment and/or telephonic communication.

Yet a further embodiment includes a partially implantable hearing system comprising an external module and an implantable module, wherein the external module includes microphone means for picking up acoustic signals, wherein the implantable module includes an output actuator arrangement for stimulation of the hearing in response to picked up acoustic signals, wherein the hearing system further comprises a transcutaneous ultrasonic communication link for ultrasonic communication between the external and implantable modules, wherein the external module incorporates means for at least transmitting ultrasonic signals containing information related to picked up acoustic signals and the implantable module incorporates means for at least receiving ultrasonic signals containing information related to picked up acoustic signals, wherein the transmitting and receiving means each include ultrasonic transducer means for converting electrical transmitter signals into information-containing ultrasonic signals and for converting information-containing ultrasonic signals into electrical receiver signals, respectively, the ultrasonic transducer means being disposed in at least close proximity to the skin of the user for transmitting and receiving, respectively, the ultrasonic signals utilizing the body of the user as an ultrasonic transmission line between the external and implantable modules.

In another embodiment, a partially implantable hearing system comprises an external module and an implantable module, wherein the external module includes microphone means for picking up acoustic signals, wherein the implantable module includes an output actuator arrangement for stimulation of the hearing in response to picked up acoustic signals, wherein the hearing system further comprises a transcutaneous ultrasonic communication link for ultrasonic communication between the external and implantable modules via modulated ultrasonic carrier signals having a frequency in the range between 100 kHz and 10 MHz, wherein the external module incorporates means for at least transmitting modulated ultrasonic carrier signals and the implantable module incorporates means for at least receiving modulated ultrasonic carrier signals, wherein the transmitting and receiving means each include ultrasonic transducer means for converting electrical transmitter signals into modulated ultrasonic carrier signals and for converting modulated ultrasonic carrier signals into electrical receiver signals, respectively, the ultrasonic transducer means being disposed in at least close proximity to the skin of the user for transmitting and receiving, respectively, ultrasonic signals utilizing the body of the user as an ultrasonic transmission line between the external and implantable modules. In a further embodiment, the frequency range is from about 500 kHz through about 2 MHz.

For still another embodiment, a hearing system comprises an implantable module that can be totally implanted, the implantable module including microphone means for picking up acoustic signals, audio signal processing means, and an output actuator arrangement for stimulation of the hearing in response to picked up acoustic signals, wherein the hearing system further comprises at least one external module selected from the group consisting of programming units, remote control units, external microphones, and signal processing and control units and any combinations thereof, and a transcutaneous ultrasonic communication link for ultrasonic communication between the external and implantable modules, wherein the external module incorporates means for at least transmitting information-containing ultrasonic signals and the implantable module incorporates means for at least receiving information-containing signals, wherein the transmitting and receiving means each include ultrasonic transducer means for converting electrical transmitter signals into information-containing ultrasonic signals and for converting information-containing ultrasonic signals into electrical receiver signals, respectively, the ultrasonic transducer means being disposed in at least close proximity to the skin of the user for transmitting and receiving, respectively, ultrasonic signals utilizing the body of the user as an ultrasonic transmission line between the external and implantable modules.

For a further embodiment, a hearing system comprises an implantable module that can be totally implanted, the implantable module including microphone means for picking up acoustic signals, audio signal processing means, and an output actuator arrangement for stimulation of the hearing in response to picked up acoustic signals, wherein the hearing system further comprises at least one external module selected from the group consisting of programming units, remote control units, external microphones, and signal processing and control units and any combinations thereof, and a transcutaneous ultrasonic communication link for ultrasonic communication between the external and implantable modules via modulated ultrasonic carrier signals having a frequency in the range between 100 kHz and 10 MHz, wherein the external module incorporates means for at least transmitting modulated ultrasonic carrier signals and the implantable module incorporates means for at least receiving modulated ultrasonic carrier signals, wherein the transmitting and receiving means each include ultrasonic transducer means for converting electrical transmitter signals into modulated ultrasonic carrier signals and for converting modulated ultrasonic carrier signals into electrical receiver signals, respectively, the ultrasonic transducer means being disposed in at least close proximity to the skin of the user for transmitting and receiving, respectively, ultrasonic signals utilizing the body of the user as an ultrasonic transmission line between the external and implantable modules. In another embodiment, the frequency range is from about 500 kHz through about 2 MHz.

All publications, patents, and patent applications cited in this specification are herein incorporated by reference as if each individual publication, patent, or patent application were specifically and individually indicated to be incorporated by reference and set forth in its entirety herein. Further, any theory, mechanism of operation, proof, or finding stated herein is meant to further enhance understanding of the present invention and is not intended to make the present invention in any way dependent upon such theory, mechanism of operation, proof, or finding. While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only selected embodiments have been shown and described and that all changes, modifications and equivalents that come within the spirit of the invention as defined herein and/or by the following claims are desired to be protected.

What is claimed is:

1. A method, comprising:

providing a hearing system including a first device spaced apart form a second device;

coupling the first device and the second device to user's body, at least one of the first device and the second device being acoustically coupled to skin of the user's body; and

performing two-way communication between the first device and the second device through bidirectional transmission of ultrasound signals through at least a portion of the user's body between the first device and the second device.

2. The method of claim 1, which includes acoustically coupling both the first device and the second device to the skin of the use's body.

3. The method of claim 1, wherein at least one of the first device and the second device includes one or more microphones.

4. The method of claim 1, wherein the hearing system includes a plurality of microphones and which includes performing adaptive beamforming with the hearing system.

5. The method of claim 1, wherein said two-way communication includes transmitting and receiving the ultrasound signals with a modulated ultrasonic carrier frequency in a range between 100 kHz and 10 MHz.

6. The method of claim 1, which includes performing digital signal processing with a digital signal processor included in one or more of the first device and the second device.

7. The method of claim 1, which includes stimulating hearing with a stimulation apparatus including in at least one of the first device and the second device.

8. The method of claim 7, wherein the stimulation apparatus includes at least one of a middle ear actuator, an electromechanical intracochlear actuator, a bone conduction cochlea stimulator, and an intracochlear electrode array.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,945,064 B2
APPLICATION NO. : 10/409970
DATED : May 17, 2011
INVENTOR(S) : William D. O'Brien, Jr. et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Col. 17, Line 18: Replace "use's" with --user's--.
Col. 18, Line 12: Replace "including" with --included--.

Signed and Sealed this
Second Day of August, 2011

David J. Kappos
Director of the United States Patent and Trademark Office